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GRAYS HARBOR NAVIGATION CHANNEL

Maintenance Dredging

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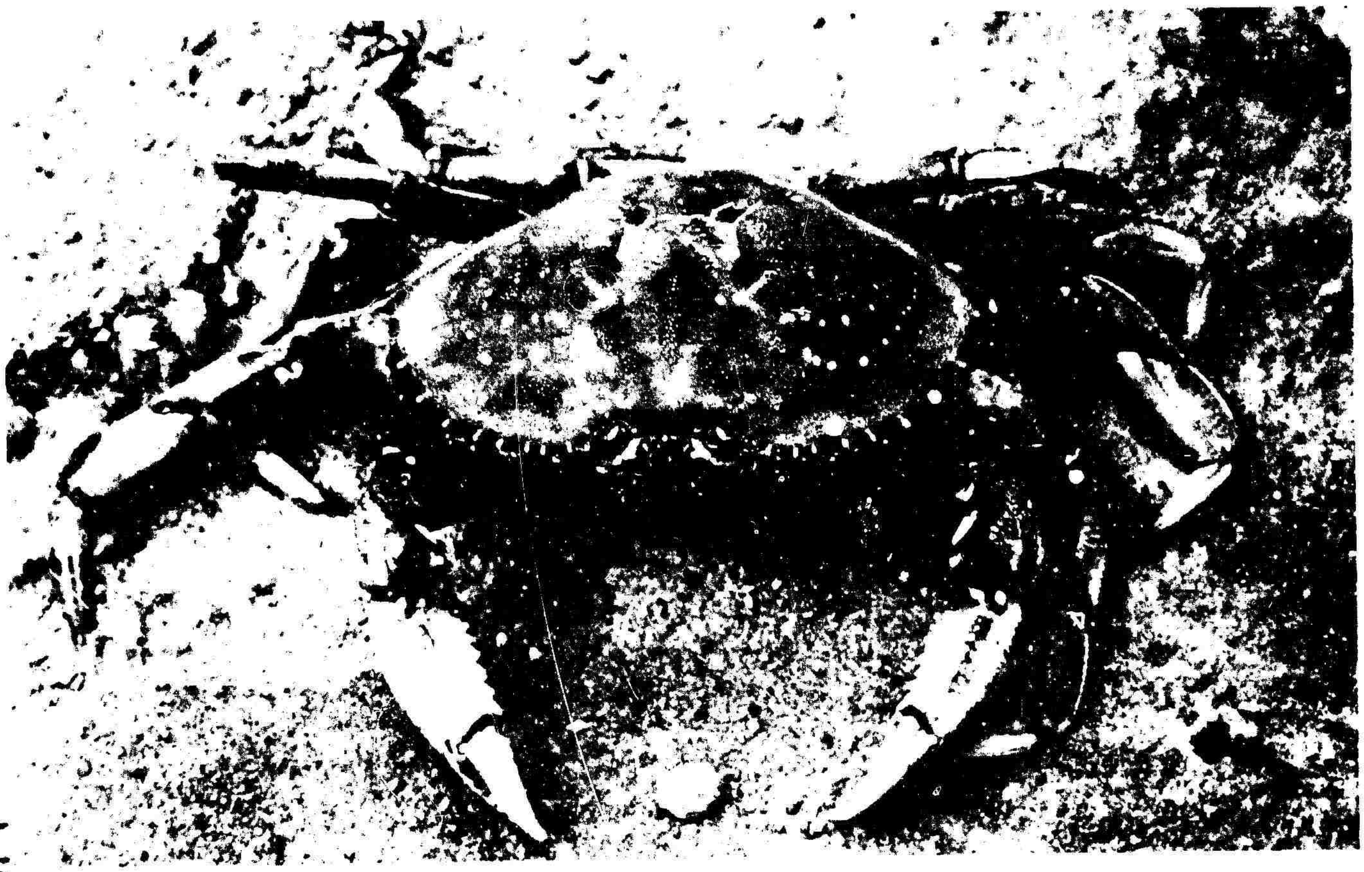
Dredging - Related Mortality of Dungeness Crabs Associated With Four Dredges Operating in Grays Harbor, Washington

II

By

BRADLEY G. STEVENS



WASHINGTON DEPARTMENT OF FISHERIES

MARCH, 1981

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From October, 1978, to December, 1979, entrainment and mortality of Dungeness crabs (Cancer magister) was estimated for two hopper dredges (PACIFIC and SANDSUCKER), a pipeline dredge (MALAMUTE), and a clamshell dredge (VIKING) operating in Grays Harbor, Washington. Sampling on suction dredges was accomplished by straining the discharged sediment through steel baskets or nylon nets, and visual observation on the clamshell dredge. Estimates of

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sampling mortality, actual dredging-induced mortality, and delayed mortality were made when possible. Entrainment rates were similar among the three suction dredges, but varied greatly with location in the harbor. Example values were 0.223 ± 0.110 crabs/cubic yard (cy) (PACIFIC, outer harbor; mean $\pm$ 1.0 std. deviation). Entrainment by the MALAMUTE was estimated to be 0.241 ± 0.185 crabs/cy in the Westport Marina, and 0.0017 crabs/cy in the Chehalis River, near Aberdeen (about 20 km upstream) where crabs were less abundant. The clamshell dredge produced the lowest entrainment rate in the outer harbor (0.012 crabs/cy), approximately 5 percent of suction dredge entrainment. Estimates of immediate plus delayed mortality were 56 percent (SANDSUCKER), 73 percent (PACIFIC), and 100 percent (MALAMUTE). Extrapolating from the above entrainment rates, and certain assumptions mentioned in the text, implies that an annual maintenance dredging of over one million cubic yards of sediment could cause potential crab mortalities of over 100,000 crabs annually, based on the dredges most commonly used in Grays Harbor.

Bimonthly fishing with crab pots at 5 locations along the navigation channel, from Westport to Aberdeen, delineated some weak seasonal changes in catch per effort.

Based on information from dredge sampling and crab trapping, recommendations were made concerning alterations in dredges and dredge scheduling which might reduce the subsequent crab mortality.

THIS STUDY WAS CONDUCTED FOR SEATTLE DISTRICT, U.S. ARMY CORPS OF ENGINEERS, BY THE WASHINGTON DEPARTMENT OF FISHERIES AND THE CONCLUSIONS PRESENTED IN THIS REPORT DO NOT NECESSARILY REFLECT THE OPINIONS OR POSITION OF THE CORPS OF ENGINEERS.

Dredging-Related Mortality of Dungeness Crabs Associated with Four Dredges Operating in Grays Harbor, Washington

March, 1981

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Olympia

U.S. Army Corps of Engineers
Contract # DACW67-79-C-0045

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ABSTRACT

From October, 1978, to December, 1979, entrainment and mortality of Dungeness crabs (*Cancer magister*) was estimated for two hopper dredges (PACIFIC and SANDSUCKER), a pipeline dredge (MALAMUTE), and a clamshell dredge (VIKING) operating in Grays Harbor, Washington. Sampling on suction dredges was accomplished by straining the discharged sediment through steel baskets or nylon nets, and by visual observation on the clamshell dredge. Estimates of sampling mortality, actual dredging-induced mortality, and delayed mortality were made when possible. Entrainment rates were similar among the three suction dredges, but varied greatly with location in the harbor. Example values were 0.223 $\pm$ 0.110 crabs/cubic yard (cy) (PACIFIC, outer harbor; mean $\pm$ 1.0 std. deviation). Entrainment by the MALAMUTE was estimated to be 0.241 $\pm$ 0.185 crabs/cy in the Westport Marina, and 0.0017 crabs/cy in the Chehalis River, near Aberdeen (about 20 km upstream) where crabs were less abundant. The clamshell dredge produced the lowest entrainment rate in the outer harbor (0.012 crabs/cy), approximately 5% of suction dredge entrainment. Estimates of immediate plus delayed mortality were 56% (SANDSUCKER), 73% (PACIFIC), and 100% (MALAMUTE). Extrapolating from the above entrainment rates, and certain assumptions mentioned in the text, implies that an annual maintenance dredging of over one million cubic yards of sediment could cause potential crab

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List of Abbreviations Used

cm = centimeter

cy = cubic yard

Dm = Discharge-minute

ft = foot

in = inch

km = kilometer

mi = mile

MLLW = Mean Lower Low Water

mm = millimeters

ppt = parts per thousand

USACE = United States Army Corps of Engineers

WDF = Washington Department of Fisheries

hr = hour

yd = yards

gal = gallons

min = minutes

kg = kilogram

SECTION 1

INTRODUCTION

A Review of Dredge-Impact Studies in the Pacific Northwest

Within the past decade, biologists have become increasingly aware of the detrimental effects of channel dredging on water quality and aquatic organisms. In the state of Washington, early research programs were aimed at defining the type and magnitude of these effects on salmon (Servize, et al, 1969), and water quality (O'Neil and Scena, 1971). Canadian biologists first observed the presence of salmon fry in the runoff from upland dredge disposal sites near Vancouver, B.C., in 1971 (Dutta and Sookachoff, 1975a). Shortly thereafter, the Fisheries and Marine Service Division of Environment Canada implemented a program to monitor the presence of salmon and other commercially valuable fish species aboard hopper and pipeline dredges. They regularly sampled the hopper overflow with dipnets to determine the possible loss of fish, but were unable to estimate the number of fish buried in the dredged material (Dutta and Sookachoff, 1975a). After several unsuccessful attempts, a method of estimating entrainment of salmon fry by a pipeline suction dredge was established (Braun 1974a and 1974b). This method, the injection of a known number of live fry into the pipeline system, showed that for every fish emerging from the disposal site drain, 21 others were lost in the disposal mass. Total mortality, established by 96 hr

viability tests, and including those fish buried, was 98.8% (Dutta and Sookachoff, 1975b).

As a result of these studies, temporary guidelines were established for dredging operations in the Fraser River. The guidelines were later modified and established as regulations by the Fisheries and Marine Service (Boyd, 1975). Further work by Canadian biologists established that dipnets could be used to effectively sample the overflow of a hopper dredge to determine the number of salmon and other fish entrained and buried in the spoil (Tutty, 1976). Once the recovery-to-entrainment ratios were determined by fry injection, one or two observers could sample a dredge continuously by dipnet, so that dredging operations could be curtailed if fish entrainment reached a critical level. Histopathological studies confirmed that entrained fish suffered extensive descaling, accidental ingestion and impaction of debris, and hemorrhagic lesions of gills, muscle, liver, and kidney, usually undetectable by casual observation (Tutty and McBride, 1976). Therefore, daily monitoring procedures were installed on all dredging operations in the lower Fraser River.

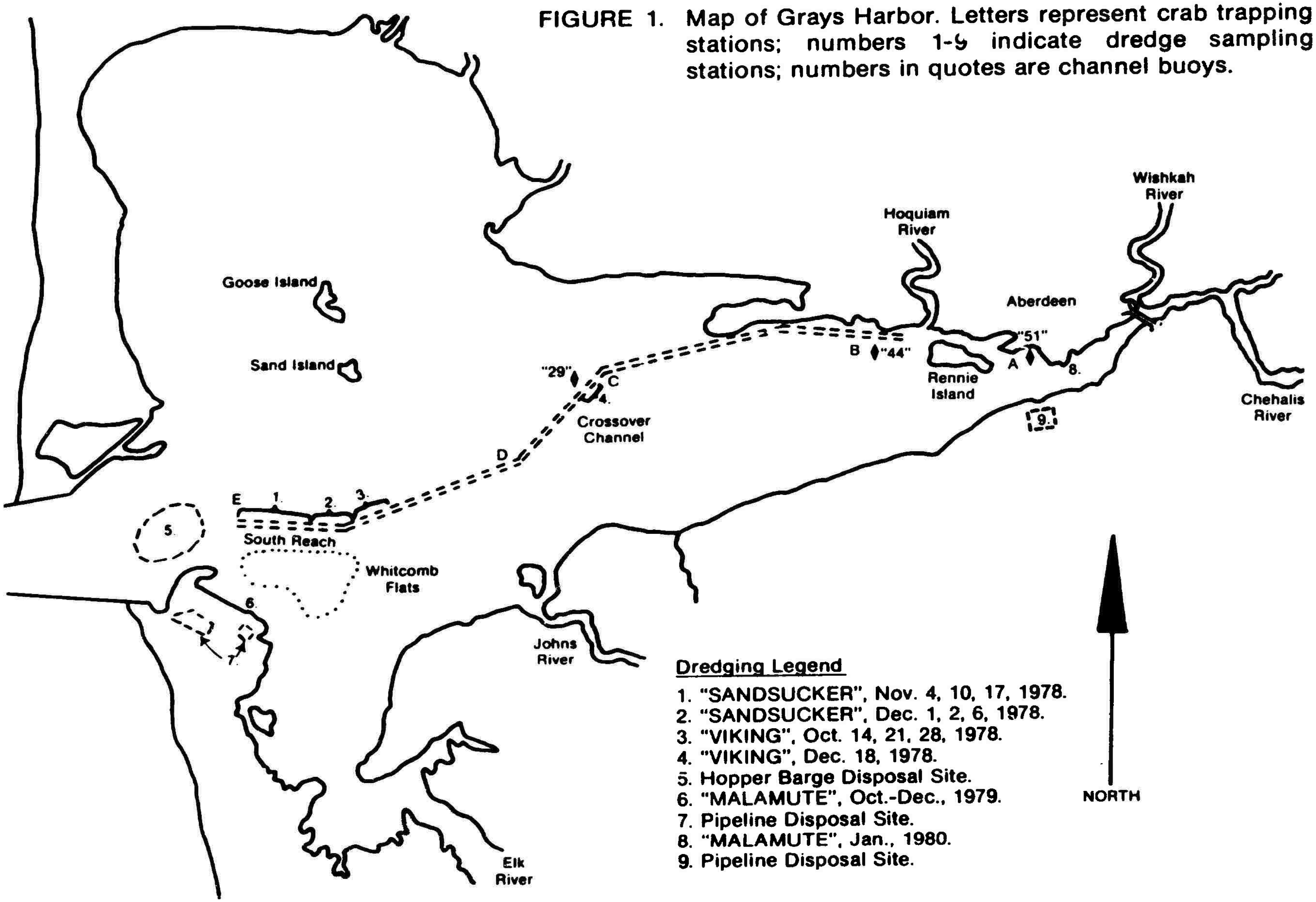
It was apparent from these and other studies that migrating fish were not the only organisms affected by dredging and disposal of dredged material. In 1972, Oregon State University conducted a short-term study of the effects of hopper dredging and disposal on sediment quality, water quality, and benthic infauna in Coos Bay, Oregon (Slotta, et al, 1972). Conclusions

of the biologists were that prior to the studied dredging operation (which removed 8,000 cubic yards (cy) during one day) the local infauna was already in an impoverished state indicative of a moderately polluted region. This fauna was adapted to almost daily physical and chemical perturbations. Diversity of organisms declined both in the dredged area and in the disposal site, as well as in nearby areas not directly affected. During this study, no attempts were made to sample epibenthic fauna such as crabs or flatfish.

In 1974, a study was initiated by the U.S. Army Corps of Engineers (USACE) to determine the effects of channel dredging on the environment and biota of Grays Harbor, Washington. This extensive study encompassed sediment and water quality effects, bioassays of disturbed water on bivalve larvae, salmon, and crabs, effects of dredging activities on vegetation, invertebrates, fish, birds, and mammals, and included the first attempts to monitor crab entrainment by a hopper dredge (USACE, 1977).

Exploratory sampling of Grays Harbor showed that many small crabs inhabited the eastern portion of the bay and the flats between the North and South Channels (Figure 1; Tegelberg and Arthur, 1977). Therefore, these areas were probably important nursery areas. Crabs were found as far upriver as the Highway 101 bridge at Aberdeen (approximately 24 km upriver from Grays Harbor mouth) in salinities as low as 9-10 ppt. No seasonal shift in crab abundances could be demonstrated. Crabs

FIGURE 1. Map of Grays Harbor. Letters represent crab trapping stations; numbers 1-9 indicate dredge sampling stations; numbers in quotes are channel buoys.



in the outer (western) portion of the harbor were mostly adult, but no gravid females were ever encountered. These findings indicated that most crabs probably migrated to the ocean upon reaching maturity.

In order to estimate crab entrainment, an airlift sampler was devised, which recovered about 1% of small crabs artificially inserted into the hopper of the dredge BIDDLE, but was incapable of sampling large volumes of dredged material. Crab mortalities observed on the BIDDLE were high (400-1,000 crabs per load of 3,000 cy of sediment) but could not be estimated reliably due to the lack of precision in this sampling method. Attempts to sample the pipeline dredge discharge produced even poorer results. However, it was noted that essentially 100% of crabs entrained by a pipeline dredge would become mortalities when discharged into upland disposal sites, and that proportionately fewer crabs were seen in pipeline discharge than in hopper dredge spoils (most likely because fewer crabs resided in the upriver areas where the pipeline dredge was operating when sampled). In bioassay studies, no crab mortalities could be attributed to the quality of water pumped into tanks from the vicinity of the dredge cutter head (Tegelberg and Arthur, 1977).

Water quality problems, and biological effects associated with pipeline and clamshell dredging and disposal were investigated in Budd Inlet, near Olympia, Washington, by the Washington Department of Fisheries (WDF) in 1975 (Westley,

et al, 1975). In spite of pre-existing water quality problems associated with Olympia sewage disposal and natural phytoplankton blooms, water from the disposal sites produced no additional toxicity to oyster or clam larvae. or juvenile salmon. Phytoplankton productivity was not inhibited, but rather enhanced. Minor decreases in dissolved oxygen and biological oxygen demand were noted in the discharge plume, but not considered significant. No major change in the distribution of benthic macroorganisms was caused by (continuous) open-water pipeline disposal, but (discontinuous) open-water barge dumping caused decreases in the number of benthic macroorganisms by burial at the disposal site. Geoduck clams were found capable of extending their siphons through up to 50 cm (20 inches) of deposited sediment. Westley, et al., did not investigate the effects of dredging on benthic epifauna.

Origin and Purpose of this Study

Due to the preliminary nature of the previous study, and continued interest by WDF biologists, the USACE supported the present study to determine the magnitude and effect of dredge induced mortality of Dungeness crabs in Grays Harbor. The present investigation establishes procedures by which crab entrainment can be estimated with some precision, and compared between various types of dredges. Various methods were used including hand-sorting and seiving the dredged material with steel baskets. Nylon nets were tried with limited success in

certain applications, and a modified basket was designed for sampling the pipeline dredge disposal.

A second goal of this study was to determine if crab movements or population density could be monitored by trapping crabs in pots. This information could then be used to improve estimates of the effect of dredging at various times and locations within the channel.

The results of this report should illuminate the possible impacts of maintenance and navigation-improvement dredging on the Dungeness crab, and perhaps indicate how some of those impacts might be lessened or alleviated.

Physical Description of Grays Harbor

The Grays Harbor estuary occupies a drowned portion of the Chehalis River mouth, located 73 km (45 miles) north of the Columbia River, at 47° N latitude, 124° W longitude. The harbor is entirely enclosed except for the mouth, which spans about 2.5 km (1.5 mi) between the north and south jetties. The estuary covers about 223 km^2 (86 mi^2) at the extreme upper limit of tidal influence, and about 99 km^2 (38 mi^2) at Mean Lower Low Water (MLLW), exposing 124 km^2 (48 mi^2) of intertidal land. The harbor averages 4.5 - 6.0 m (15-20 ft) deep at MLLW. Extreme spring tide range is from 0.64 to +3.8 m at Aberdeen, located at the eastern end of the harbor, but mean yearly ranges in the harbor are about 2.1 m (7 ft). The area receives 1.8 to 2.5 m (70-100 in) of rainfall yearly, and the

combined inflow from six river systems averages 10,500 cu. ft. per sec., of which about 80% originates from the Chehalis River system. Water volume varies from 5.1×10^8 cy at MLLW to 13.7×10^8 cy at the upper limit of tidal influence. Depending on season and location in the harbor, water temperatures range from 3.3 to 21.1° C (38-70° F). Salinities range from 0 to 33 ppt (USACE, 1977).

The Channel and Dredging Activities

At the start of this project in October 1978, the main ship channel was about 37 km (23 miles) long, 9.1 m (30 ft) deep, and 60-180 m (200-600 ft) wide. Most of this channel was maintained by dredging, which removed a yearly average of 2.1 million cy of sediment during the period 1971-1974. 1.8 million cy were removed in 1975, and about 1.3-1.5 million cy has been removed annually by maintenance dredging in the period 1976-1979. Approximately half of this material is dumped subtidally, and the other half is disposed of on uplands.

Two dredges sampled during this study, the SANDSUCKER and VIKING, created a new channel section (the South Reach). This connection between the Crossover Channel and Grays Harbor entrance replaced the Sand Island Reach, which is no longer maintained. This modification was expected to produce about 3.0 million cy of dredge material, and reduce the required annual maintenance dredging by 0.25 million cy.

Presently, plans are being made for enlarging the channel, deepening it by aproximately 3 m (10 ft) and widening it by about 30 m (100 ft). The widening and deepening will require removal of about 19.4 million cy of sediment, with subsequent maintenance dredging of 2-3 million cy per year.

The results of this report should illuminate the possible impacts of such a vast dredging program on the Dungeness crab, and perhaps indicate how some of those impacts might be lessened or alleviated.

SECTION 2

SAMPLING ABOARD THE CLAMSHELL DREDGE "VIKING"

The clamshell dredge VIKING, owned and operated by Manson Construction and Engineering Company, of Seattle, Washington, consisted of a large revolving derrick permanently mounted on an unpowered barge. Suspended from the derrick was a bucket with a split vertical seam, which opened and closed much like a clamshell, hence the name for this type of dredge. Since it was unpowered, major movements of the VIKING were accomplished with the aid of a tug. Once anchored in place, however, the VIKING could be repositioned several hundred feet in any direction by altering the length of its anchor lines. From the stationary barge, the bucket could be deployed anywhere within a 50 m (164 ft) radius. Maximum capacity of the bucket was about 14 cubic yards (cy). Buckets of dredged sediment were dumped onto a barge which was later towed away by a tug and emptied by open-water dumping. The VIKING could remove approximately 500 cy of sediment per hour when operating at normal capacity.

METHODS AND MATERIALS

Sampling of the VIKING was conducted on October 14, 21, and 28, 1978, during which the VIKING was operating near the SE end of the Crossover Channel (Figure 1). Additional sampling was completed on December 18, 1978, at which time the VIKING

was repositioned in the northern end of the Crossover Channel. On each of these days, 5 or 6 dredge buckets full of sediment were collected from selected locations around the area being dredged. Some samples were taken from the channel being dug, others from outside the channel margins. Samples were placed on an empty barge, and estimates of their volume were provided by the dredge operator. Type and consistency of the sediment was noted, as well as the presence of shells or sticks. Samples were examined visually by raking and digging through the top 30-40 cm (12-16 in) of material, then washing it down further with a stream of water from a gasoline-powered pump. The amount of material actually examined (subsampled) was estimated. Live macroscopic organisms were collected, counted, and later identified.

During the latter three sampling periods, an electronic probe was used to record water temperature and salinity at 3 m depth intervals at the dredging site.

During sample periods in October, crab pots baited with razor clams were set near the VIKING. Pots were set 1-2 days before dredge sampling, then recovered on the sampling date. On October 21 and 28, 1978, the baited pots were replaced in the water for another 2 days, during which the VIKING was not operating. After removal from pots, crabs were sexed and measured. On December 7, eight ring nets baited with fish heads were set at a depth of 25 ft about 1 km NE of VIKING (set "a"). Ring nets were also set about 500 m south of VIKING, in

10-15 ft of water on the north edge of Whitcomb Flats (set "b"). Nets were fished for 20 minutes, after which they were pulled. Crabs were then sexed and measured to the nearest millimeter across the back of the carapace, between the notches just anterior to the tenth anterolateral spines.

Samples of dredged material in October were taken from locations relatively close to each other, near the intersection of the Crossover Channel, and the new (South Reach) channel between buoys 24 and 25. On December 18, the VIKING was moved into the Crossover Channel between buoys 28 and 30, approximately 2 miles north of the site where the previous samples were collected. On the latter date, 8 ring nets were set for 20 minutes from the deck of the VIKING. Captured crabs were sexed and measured.

RESULTS

During four days of sampling effort, 23 samples ranging in size from 4-12 cy were selected for examination. From each sample, a subsample of 1.5-8 cy was examined visually (Table 2-1). Of the total 168 cy sampled, 86.5 cy, or about 51% was examined for crabs. One crab was found, for a catch rate of 0.012 crabs/cy. VIKING sampling locations were described by U.S. Army Corps of Engineers (USACE) Lambert coordinates (Appendix A). Descriptions of dredged material are given in Appendix B. Samples were taken from depths of 14.5 to 33 ft

Table 2-1. Depth and size of VIKING samples and subsamples.

Date	Sample #	Depth[1] (ft)	Sample volume (yd^3)	Subsample volume (yd^3)	Tide
10/14/78	1.1	-	5	3	Middle flood
	1.2	-	5	3	
	1.3	-	4	3	
	1.4	-	10	8	
	1.5	-	12	6	
10/21/78	2.1	33	5	3	Middle ebb
	2.2	33	6	4	
	2.3	14.5	5	3	
	2.4	29.5	14	4	
	2.5	19	8	7	
	2.6	21	9	8	
10/28/78	3.1	19	5	2.5	Middle flood
	3.2	20	8	4	
	3.3	33	4	2	
	3.4	33	6	3	
	3.5	22	7	3.5	
	3.6	22	6	3	
12/18/78	4.1	15	10	4	Middle flood
	4.2	15	7	2.5	
	4.3	15	7	2	
	4.4	20	7	3	
	4.5	19	7	3.5	
	4.6	18	11	1.5	
			168	86.5	

[1]Depth below MLLW

below MLLW. All samples were taken during periods of high current velocity during flood or ebb tide.

Live organisms were found in all samples taken from bottom areas not previously dredged (Table 2-2). Live organisms were also found in all samples taken from the Crossover Channel on 12/18/78; this area had not been dredged for 14 months. Virtually no live macroscopic organisms were found by visual

Table 2-2. Numbers of live organisms in VIKING samples. Samples segregated by dredging history.

Dredge History Group[a]	Sample #	*Cancer magister*	*Callianassa califoriensis*	*Upogebia pugettensis*	*Mya arenaria*	*Tresus canax*	*Clinocardium nuttali*	*Macoma nasuta*	*Macoma sp.*	*Nephtys caeca*	*Nereis sp.*	*Leptocottus armatus*	Unknown annelid	Unknown amphipod
A	1.4	b	759						548	24				10
	1.5		235						193	20				
	2.3	b	512						62	19				
	2.5		156						46	11				
	2.6		7							10				
	3.1		234						62	27			3	
	3.2	1	168						80	14			1	
	4.1		49	3	1			1						
	4.2		31	1		1	1	1			1			
	4.3		26	1		1		1						
	4.4		19				1				4			
	4.5		20		1	1					2			
	4.6											2		
B	1.3													
	3.3	b												
	3.4													
C	1.1		3											
	1.2		1											
	2.1	b												
	2.2													
	2.4												1	
	3.5													
	3.6													

a/ Dredge History Groups:
A. Not dredged for about 1 year.
B. Dredged within previous 12-24 hours.
C. Old cuts; dredged several weeks prior to sampling.

b/ Portion of claw or shell, apparently molted or discarded.

examination in those samples from bottom areas that had been dredged within the previous 3-4 weeks. Broken or discarded mollusc shells were found in many samples, especially those that had undergone previous dredging (thus taken from greater depths; Table 1, Appendix B). One crab, alive and apparently unharmed (78 mm female) was found in sample 3.2 (10/28/78). This sample was taken from an undredged area southeast of the new channel being cut. In four other samples were found a single claw or shell portion (Table 2-2); no tissue was present in any of these, thus it was concluded that they were molted or discarded.

Crabs were caught whenever pots or ring nets were set, even from the deck of the VIKING during sediment sampling (Table 2-3). Salinity and temperature profiles taken during sampling periods 2 (10/21/78) and 3 (10/28/78) were similar; only sampling location 4 (12/18/78) was substantially different from locations 2 and 3 (Figure 2).

DISCUSSION

The VIKING samples were only grossly examined. Estimates of their volume could have been in error ±25%. However, the discovery of only one crab in 86.5 cy of sampled material indicates that this type of dredge collects or directly harms very few crabs. Of the bottom samples examined, only the surface sediment was afforded careful examination. Although

Table 2-3. Crabs caught by pots or nets near VIKING.

Date of set	Locations of pots/nets	No. of Pots (P) or nets (N)	Time fished	Mean No. of crabs/trap	Avg. size (mm)	% Males
10/14/78	750 m. N. of VIKING	4 P	26 hr	15.3	144.2	100
10/19/78	100 m. E. of VIKING	4 P	49 hr	17.2	141.0	97
10/21/78	Same as above	4 P	47 hr	18.5	146.0	95
10/26/78	Same as above	3 P	25 hr	23.7	134.8	94
10/28/78	Same as above	3 P	49 hr	16.7	146.8	98
12/7/78(a)	1000 m. NE of VIKING	8 N	20 min	40.4	89.4	69
(b)	N. edge of Whitcomb Flats, 500 m. S. of VIKING	8 N	20 min	6.9	98.8	91
12/18/78	From deck of VIKING	8 N	20 min	10.2	88.5	80

this material represented only 51% of the total sample volume, the majority of benthic organisms were probably contained in this fraction. Hypotheses to explain the low observed mortality are as follows: 1) No crabs lived in the area dredged; 2) Any crabs in the area had been killed by previous dredging; 3) Dredging removed all prey organisms, thus rendering the area unattractive to crabs; 4) Crabs avoided the dredge; 5) Crabs escaped from the dredge bucket.

Data from crab pots and ring nets shows that crabs were abundant in the dredged areas (Table 2-3). Although no crabs were recovered from 10 samples from previously dredged areas, only one crab occurred among 13 samples from virgin ground (Table 2-2).

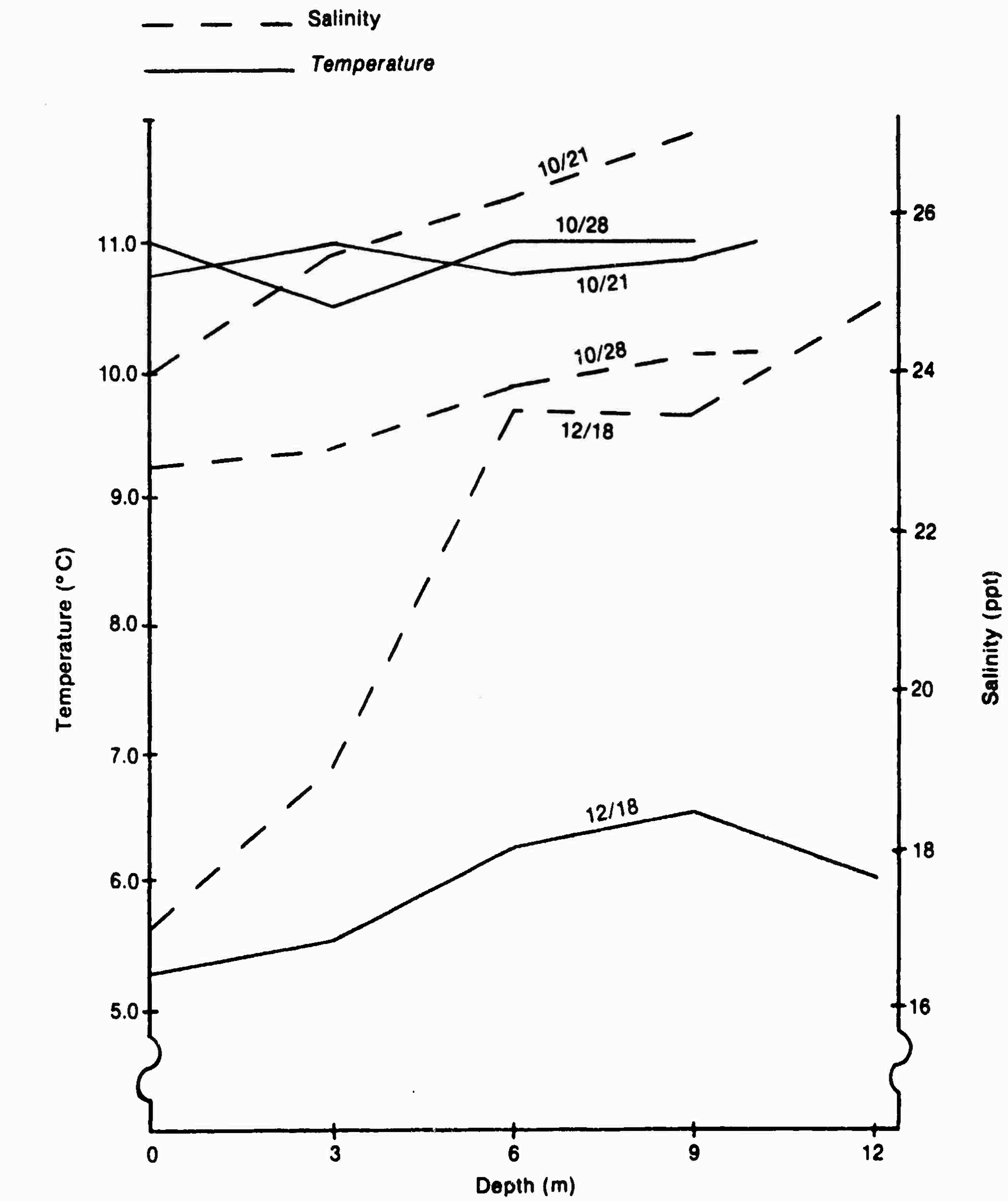


FIGURE 2. Temperature and salinity profile of locations sampled by "Viking".

Dredging removed prey organisms, at least temporarily. This was shown by the abundance of invertebrates in samples from virgin ground, and their virtual absence from samples from previously dredged areas (Table 2-2). Whether or not this lack of prey would cause the complete absence of crabs is not known.

Since very few crabs were found in the material dredged by the clamshell method, it seems likely that crabs can avoid the VIKING. Such avoidance might be due to two factors: 1) Physical disturbance of the bottom by the dredge increased the turbidity of the water and its suspended sediment content: 2) Crabs may be alerted by the great commotion that occurs when dropping the bucket into the water. Such commotion might include a pressure wave preceding the sinking bucket and low frequency vibrations as a result of splashing at the water surface. Dungeness crabs are capable of swift movement, and may actively avoid the dredge. Water turbidity might have interfered with respiration or visibility, thus rendering the area less attractive to crabs. However, crabs might also be attracted to a dredging site by the number of prey organisms loosened or stirred up by the dredge. Crabs were collected in ring nets set immediately below the VIKING, even during the dredging process.

The bucket of the VIKING is completely open at the top; the surface of the contained material often lay only a foot or less below the rim of the bucket. Often, the dredge operator allowed the full, closed bucket to remain submerged as excess water drained out of it. These factors might have contributed to escape of crabs from the bucket.

VIKING personnel indicated that they have occasionally observed crabs on the surface of the dredged material in other seasons of the year. Thus, there was prior basis for belief that VIKING does catch crabs, although such was not the case during this study.

Only one crab was recovered from 23 sediment samples examined. Thus no confidence interval could be calculated about the mean (0.012 crabs/cy). Similarly, no reasonable estimate of crab survival or mortality could be made. For the single crab discovered, survival was 100%. The VIKING was operating in Grays Harbor for 16 months (August 1977 to December 1978) during which it removed 1.7 million cy of sediment. If the observed entrainment rate is assumed to be reasonably accurate, and allowing for $\pm 25\%$ error in sample size estimation, the number of crabs entrained during that period of time may have ranged from 15,300 to 25,500 ($\bar{x}$ = 20,400). Mortality, though it could not be estimated, was probably much lower than that for suction dredges (see Section 6: Comparison of Crab Entrainment and Mortality aboard Four Dredges).

More crabs were caught in crab pots than in ring nets. This difference was probably due to the design of the gear, and the length of time fished (1-2 days vs 20 minutes). Pots are size-selective gear. Larger mesh size allowed escape of smaller crabs, which may have been driven out by adults.

Similarity of the temperature/salinity profiles taken on October 21 and 28 was probably due to the proximity of the locations, which were about 150 m apart (Figure 2). Sample location 4 (12/18/78) was situated several miles north (upstream), thus accounting for the difference from sample locations 2 and 3. Although higher salinity was recorded on 10/21/78, it is interesting to note that the former was during ebb tide, and the latter during flood.

SUMMARY

1) During four test periods aboard the VIKING, 168 yd^3 of material were sampled. Of this amount, 51% (86.5 yd^3) was visually examined, including all material on or near the sediment surface.

2) Only one crab was found, alive and unharmed; the calculated entrainment rate was 0.012 crabs/cy.

3) Estimates of survival could not be extrapolated to large volumes of sediment, due to the low number of crabs recovered.

4) Other crabs were captured in pots or ring nets whenever set beneath, beside, or behind the operating dredge.

5) The most likely hypotheses explaining the low observed entrainment rate are:
   a) Avoidance of the dredge bucket by crabs; or
   b) Crabs were swept away by a pressure wave preceding the bucket as it descended.

SECTION 3

SAMPLING ABOARD THE HOPPER-BARGE SANDSUCKER

Manson barge #56, referred to as the SANDSUCKER, is a suction type hopper dredge, employing a single intake arm and suction head (Figure 3). Fill capacity was about 1500-1600 cubic yards requiring 2.5-3.0 hours of pumping. After entering the suction head, sediment passed through a 20-inch diameter intake arm, then through an impeller of similar width which operated at roughly 400 rpm and propelled the sand-water mixture up into the discharge pipe. The single discharge pipe extended centrally along and above the entire length of the hopper, which was 14 ft deep. A catwalk ran along one side of the pipe. Along the bottom of the discharge pipe were eleven ports through which the sediment was expelled into the barge. A greater proportion of sediment was expelled through the first few ports, due to their proximity to the impeller; discharge from the distal openings becomes progressively less with distance from the impeller. The first port discharged very little: it is placed just beyond an elbow in the discharge pipe. Presumably the speed of the sand-water mix at this point was such that little could settle out there. Being unpowered, the SANDSUCKER was pushed by a tug. Hence, the term hopper-barge is applied to this type of dredge.

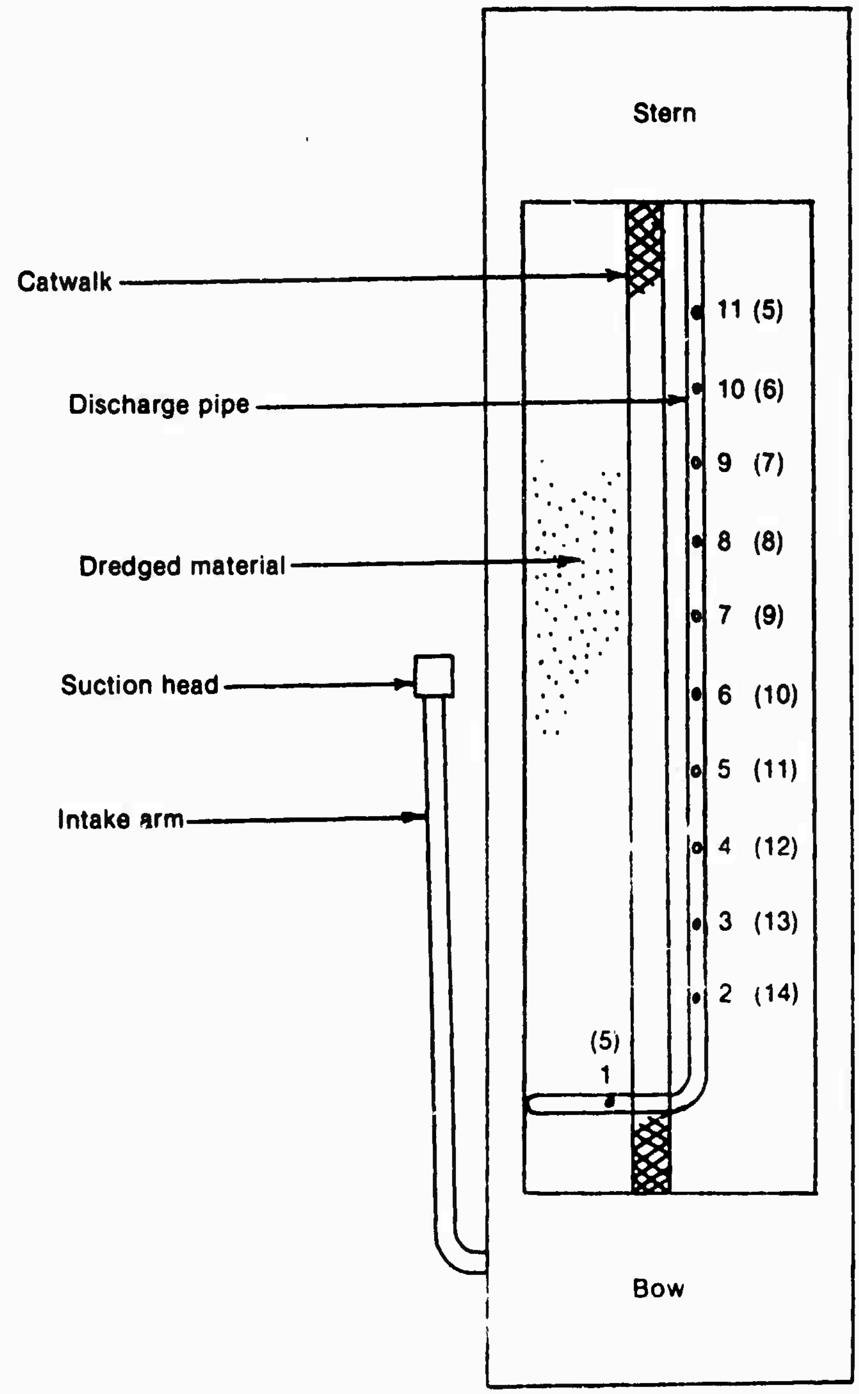


FIGURE 3. Design of Manson barge #56 (SANDSUCKER). Holes numbered from bow to stern. Numbers in parentheses are estimated % of total discharge expelled at each hole. Scale 1:300 (1"=25').

METHODS AND MATERIALS

Sampling aboard the SANDSUCKER was conducted on November 4, 10, and 17, and December 1, 2, and 6, 1978.

In order to assess differences in the discharge that resulted from differing water pressures at each opening, and distance from the impeller, ports 3, 5, 7, and 9 were selected for sampling. On top of the discharge pipe at each selected sampling port, we mounted a bracket designed to support a moveable davit. The procedure for sampling a given port is described below.

Collapsible sampling baskets were made of expanded steel with diamond-shaped mesh 44 mm (1 3/4 in) on long axis by 16 mm (5/8 in) on short axis. Baskets were 35.6 x 40.6 x 76.2 cm (14 in x 16 in wide, and 30 in deep). Using a block and tackle suspended from the davit, the basket was hoisted from the catwalk, over the top of the pipe, around the far side, and positioned below the port. Chains were then used to secure the basket, which hung 30-60 cm (1-2 ft) below the hole being sampled. The amount of time during which sediment was passing through the basket was recorded to the nearest minute.

A typical dredge-loading cycle lasted about 4 hours, including 4-5 passes over the dredging site. Each pass lasted about 30-45 minutes, during which sediment pumping occurred. These passes were interrupted by intervals of about 20 minutes during which the dredge was turned around, and pumping was discontinued; such times were not recorded as pumping time or

sampling time. Occasionally during dredging, the suction head would lift off the channel bottom so that only clean water was being discharged. These occasions amounted to only about 5-10 minutes total during any particular dredge-loading cycle. Although they were not included as sampling time, they are included in the total pumping time for each load.

On any particular day of sampling, each opening was sampled at least once, for a total of 20-40 minutes of sample time. Attempts were made to sample each port for the same amount of total time each day, but this was usually not feasible. It was usually necessary to sample each port for several separate periods of 5-20 minutes duration, because the baskets would begin to fill up with sticks and sand. When full, baskets were raised and set down on the catwalk. Two sides of the basket were opened out along the catwalk, and workers sorted through the trapped debris. Sorting was done by lifting or scraping debris from the central pile out onto the lowered basket sides, picking out whole or partial organisms, and discarding the sand and sticks. The basket was then replaced to continue sampling, or moved to another opening.

During several sampling days, the work party had the opportunity to remain aboard the barge during dumping. On these occasions extra (surface) crabs were collected from the surface of the dredged material for examination of damage. Others were observed while being dumped back into the water.

On return to the laboratory, all organisms were examined and identified. Crabs were examined for damage, then either discarded, dissected, or, if alive, kept overnight in aquaria. Major carapace portions (25% of whole carapace) were counted as individual crabs if they contained some tissue (i.e., were not molted shells) and could not be matched up with any other portions found in any sample on that particular day.

Treatment of Data

For purposes of calculation, the proportion of the total sand-water mix expelled from each port was estimated, and is given in Figure 3. Although they could not be made with complete accuracy, these estimates were thought to be as correct as possible, considering the method employed. Two different methods of mortality estimation were used.

Method 1: Sampling time for each port was adjusted by the formula:

(Sample time) x (% flow) x (% discharge) = Discharge minutes (Dm)

where sample time = time recorded while basket received discharge from port.

% flow = proportion of material exiting $port_n$, that actually passed through basket.

% discharge = estimated proportion of all pumped material which exited via $port_n$.

A discharge minute (Dm) was defined as a hypothetical unit equivalent to one minute of sediment pumping by the dredge. Adjusted sample times expressed as (x) Dm were therefore equivalent to sampling (x) minutes of discharge pumping at the point of intake, i.e., the suction head. Due to the presence of 11 discharge openings, and the fact that only about 80% of the material exiting from the sampled openings actually passed through the basket, any basket received an average of 7.3% of the total sediment taken in during any one minute of dredge operation, i.e., an amount of sediment representing 0.073 Discharge minute. Therefore, 13-14 minutes of sampling at the discharge openings were required to sample an amount of material equivalent to the total sediment load which would be taken up during one minute of pumping (one Discharge-minute).

Method 2: Method 2 was essentially similar to method 1 with this exception: instead of using a different estimated value for % discharge at each port, the value used in each case was the overall average of 9.1% (100%/11 ports).

For each day of sampling, the weighted average of crabs collected by the dredge per minute of operation (C/Dm) was calculated by the formula:

$$C/DM = \frac{\sum_{n=1}^{4} C_n}{\sum_{n=1}^{4} Dm_n} = \frac{\text{Sum of all crabs collected on Day i}}{\text{Sum of Discharge minutes sampled on Day i}}$$

wherein C_n = number of crabs sampled from $port_n$.

Dm_n = total discharge minutes sampled at $port_n$.

Total crabs per hopper load or per day were calculated by multiplying C/Dm by total pumping time per load, or per day, respectively. For comparison, Dm and C/Dm were also calculated for each individual port.

Damage comparison

Body damage was compared between sampled and surface-collected crabs. Upon examination, damage was recorded in six categories: 1) No observable damage (alive or dead); 2) Smashed (therefore dead, regardless of missing legs); 3) 1-2 legs autotomized or damaged distal to the autotomy plate; 4) 3 or more legs autotomized or damaged distal to the autotomy plate; 5) Breaks in coxae or bases (leg segments proximal to the autotomy plate); 6) Major cracks or punctures in carapace, sternum, or abdomen. Categories 1 and 2 were exclusive, i.e., crabs listed there do not appear in any other category, whereas categories 3-6 were not exclusive, and included dead crabs as well as live ones.

Crabs damaged directly by the dredge were easily distinguishable from crabs damaged before encounter with the dredge by the presence of limb buds, or the darkened color of healing wounds.

Autopsied crabs were dissected and examined for the presence of sand in the heart, gill arteries, or anywhere internal to the epidermis.

Selected damaged or uninjured crabs were placed in aquaria for 24-48 hours to assess survival after capture.

Crab sampling near dredge

On December 7, 1978, ring nets and a 1.8 m beam trawl (6 ft) were used to capture crabs along the north edge of Whitcomb Flats (Figure 1). Eight nets were set in 10 ft of water. The nets were arranged in a line running east-west about 300 m (approx. 1000 ft), just south of buoy 24. After 20 minutes, nets were pulled and emptied; crabs were sexed and measured. The beam trawl was pulled parallel to the nets for 10 minutes.

RESULTS

The SANDSUCKER operated in two different locations during the study. During sample periods 1-3 (November, 1978) the dredge was operating between stations 665 and 683 (a distance of approximately 1800 feet - Figure 1). This area had been dredged intensively before sampling began. During sample periods 4-6 (December, 1978) the dredge was operating between stations 700 and 740, covering about 4000 feet. The latter area had not been dredged for about 1 year. These two areas were considered representative of normal maintenance dredging

operations and results from both areas were combined for purposes of calculation.

During six days of sampling, 90 whole crabs, and carapace portions representing 17 others killed by the dredge, were

Table 3-1. Crabs in SANDSUCKER samples.[1]

Sample period		Port #	Number of Crabs Alive	Dead	Portions	Total
1	11/4/78	3	*	*	*	
		5	0	2	0	2
		7	0	1	1	2
		9	0	1	0	1
						5
2	11/10/78	3	3	5	4	12
		5	0	2	1	3
		7	4	5	4	13
		9	0	2	0	2
						30
3	11/17/78	3	2	0	0	2
		5	0	0	0	0
		7	3	1	0	4
		9	1	0	0	1
						7
4	12/1/78	3	0	0	1	1
		5	0	1	1	2
		7	1	0	0	1
		9	3	2	0	5
						9
5	12/2/78	3	2	1	0	3
		5	4	6	3	13
		7	1	4	0	5
		9	7	5	0	12
						33
6	12/6/78	3	1	4	1	6
		5	3	4	1	8
		7	2	4	0	6
		9	1	2	0	3
						23
Total			38	42	17	107

*No sample taken
[1]Including crabs seen to escape from baskets

Table 3-2. Numbers of individuals of other species in SANDSUCKER samples.

Species	Sample period					
	1	2	3	4	5	6
Leptocottus armatus (staghorn sculpin)		7	6	16	1	1
Enophrys bison (buffalo sculpin)			1			
Citharicthys sordidus (pacific sanddab)	1	1	1	4		2
Parophrys vetulus (English sole)			1			
Syngnathus leptorhynchus (bay pipefish)			1			
Psetticthys melanostictus (sand sole)			1			
Crangon franciscorum (sand shrimp)		1	4	1		2
Callianassa californiensis (ghost shrimp)	3	17			12	8
Siliqua patula (razor clam)		1			2	2
Nephtys caeca (polychaete)	2	4			1	
Glycera sp. (polychaete)		1				
Ophelia limacina (polychaete)				2		

collected in sampling baskets (Table 3-1). Other organisms collected included 6 species of fish, 2 crustacean species, razor clams, and 2 species of annelids as well as infrequent fragments of algae (Table 3-2).

The number of crabs collected, divided by the number of discharge minutes (Dm) sampled, provided an estimate of the number of crabs (C) picked up by the suction head per minute (C/Dm). This number was calculated for each discharge port, by day, or for all samples combined, according to two different methods discussed previously. According to method 1 or 2, total Dm sampled were 54.6 or 51.8 respectively (Table 3-3). The difference between the two estimates was caused by the use of two different sets of estimated values for % discharge at each opening in the discharge pipe. Averaging the results over 6 test periods gave catch rates of 1.89 $\pm$ 0.98 C/Dm, and 1.98

±1.05 C/Dm, for methods 1 and 2 respectively ($\bar{x} \pm$ 95% confidence interval). Daily estimates of C/Dm obtained by each of the two methods were compared by a two-sample paired "t"-test (Table 3-3). A pooled variance of 0.94 and "t" value of 0.161 were obtained, with 10 degrees of freedom. This value of "t" was not significant at any value of $\alpha < 0.50$. Therefore, there

Table 3-3. Adjusted sample times and rates of crab catch aboard SANDSUCKER[1]

Sample period	Total crabs	Method 1 Discharge minutes	Method 1 C/Dm	Method 2 Discharge minutes	Method 2 C/Dm	Average C/Dm
1	5	4.20	1.19	4.47	1.12	
2	30	10.2	2.95	9.60	3.12	
3	7	4.61	1.52	4.36	1.61	
4	9	13.2	0.68	12.2	0.74	
5	33	11.2	2.95	10.6	3.11	
6	23	11.2	2.05	10.6	2.16	
Total	107	54.6	11.34	51.8	11.86	
$\bar{x}$			1.89		1.98	1.94
standard deviation			0.93		1.00	
95% confidence interval			0.98		1.05	1.02

Two-sample "t"-test		Method 1 vs Method 2
pooled variance	(s^2)	= 0.094
pooled standard deviation	(s)	= 0.56
degrees of freedom		= 10
test statistic (t)		= 0.161
critical value ($t_{10, 0.05}$)		= 2.228
significance level		none

[1]Crab catch rate in terms of crabs/discharge minute (C/Dm)

was no significant difference between the mean estimates of entrainment rate (crabs per discharge minute) provided by the two different methods of calculation. Henceforth, their average value of 1.94 $\pm$ 1.02 C/Dm will be used.

Approximately 172 minutes were required to fill the hopper (average of six observed loads). Therefore, an average barge load would have contained 334 crabs (range = 158 to 509). Estimates of total crabs caught in actual sampled hopper loads ranged from 143 (Sample 4, method 1) to 544 (Sample 5, method 2; Table 3-4). The SANDSUCKER completed 5 or 6 loads in 24 hours of continuous operations. Employing an average fill time of 172 minutes, and the lowest and highest confidence limits about the entrainment rate, the number of crabs captured during a 24-hour period would range from 790 to 3,054 (5 or 6 loads, respectively). To illustrate how averaging effectively reduced the estimated mortality ranges, calculations were also made employing actual catch rates and pump times from sampled hopper loads. Thus, the range of catch rates might be 715 crabs/day (5 loads like sample 4) to 3,264 crabs/day (6 loads like sample 5). These figures illustrate that the range of actual crab mortality may exceed the range calculated from average expectations. The highest rate of crab discharge calculated by method 1 occurred from port #7 ($\bar{x}$ = 2.60 C/Dm); the lowest, from port #9 ($\bar{x}$ = 0.96 C/Dm; Table 3-5). These values were not statistically compared. Problems with extrapolation of the above mortality estimates are reviewed in the discussion.

Table 3-4. Timing of SANDSUCKER sampling periods.

Sample Date	1 11-4-78	2 11-10-78	3 11-17-78	4 12-1-78	5 12-2-78	6 12-5-78
Start time	0900	0825	1242	1300	0815	1231
Stop time	1130	1101	1530	1510	1011	1543
Tide[1]	low slack	low slack	high slack	high slack	low slack	early flood
Closest slack	0940	0931	1417	1326	0839	1220
Pump time[2]	155	140	170	210	175	180
Crabs/load:						
Method 1	184	413	258	143	516	369
Method 2	174	437	274	155	544	389

[1]Tide based on Aberdeen (NOAA tide schedule).
[2]Minutes of pumping required to fill hopper.

Table 3-5. Rates of crab entrainment measured at various distances along SANDSUCKER discharge pipe. Values expressed as # crabs/discharge-minute.

Sample #	Port # 3	5	7	9	Weighted avg.
1	No data	1.36	1.48	0.58	1.19
	3.97	1.35	5.12	0.84	2.95
3	1.25	0.00	3.48	0.86	1.52
4	0.26	0.61	0.28	2.08	0.68
5	1.36	3.27	2.00	0.48	2.95
6	1.92	2.59	3.26	0.95	2.05
Non-weighted avg.	1.75	1.53	2.60	0.96	

Dredging Related Mortality

In the sampling baskets 61% of collected crabs died, compared to only 30% of the surface-collected crabs (Table 3-6). Death was due in large part to the effects of being smashed against the sides or bottom of the basket by water pressure, or by large sticks raining down upon the trapped crabs. Of sampled crabs 42% were smashed compared to only 19% of surface crabs. The proportion of crabs that passed through the dredge unharmed was greater for surface crabs (19%) than for sampled crabs (6%; Table 3-6). In intermediate damage categories, the proportion of crabs was surprisingly similar between sampled and surface crabs. Dead crabs included all those listed as "smashed", many of those with carapace cracks and punctures, and a few of those with damage to the coxae and bases (leg segments proximal to the autotomy plate). Aside from complete crushing, two probable causes of death were noted. These were loss of blood, due to major breaks in the carapace, and the presence of sand inside the gill arteries and/or lamellae. Of 19 crabs autopsied (sample periods 5 and 6) all 7 dead ones contained sand in the gill arteries, while 8 of 12 moribund crabs also contained sand in the gills.

Table 3-6. Comparison of damage between sampled and surface-collected crabs.

Damage category[1]	Sampled #	Sampled % of N	Surface #	Surface % of N
No damage	6	6	9	17
1-2 legs missing or damaged beyond autotomy plate[2]	24	24	12	22
3 or more legs missing or damaged beyond autotomy plate	9	9	4	7
Breaks in segments proximal to autotomy plate	26	26	12	22
Punctures or cracks in carapace, sternum, abdomen	35	35	21	39
Smashed	42	42	10	10
Total considered (N)	100		54	
Alive[3]	39	39	38	70

[1]An individual crab may be included in more than one category, except for "No damage" and "Smashed", which are exclusive.

[2]Autotomy plate lies at junction between basis and ischium.

[3]Alive at time of examination in lab, usually 2-5 hours after collection, occasionally more.

When compared by a two-sample "t"-test (for unequal sample sizes) there was no significant difference between the average size of crabs sampled on the dredge ($\bar{x}$ = 81.5 mm) and crabs caught near Whitcomb Flats ($\bar{x}$ = 98.8 mm; Table 3-7 and Table 3-8). Although there were noticeable differences between the mean carapace widths of these two samples, lack of significance was probably due to the great amount of variability within the Whitcomb Flats sample, which included crabs from 66 to 158 mm; the coefficient of variation for this sample was 0.95.

Table 3-7. Size of trapped crabs in millimeters $\pm$ one standard deviation.[1] Number of crabs measured in parentheses.

Origin	Cumulative	Alive	Dead
Whitcomb Flats (ring nets)	98.8 $\pm$ 93.7 (55)		
Sampled (dredge)	81.5 $\pm$ 16.3 (87)	76.2 $\pm$ 11.7 (37)	85.9 $\pm$ 18.3 (44)
Surface (dredge)	87.9 $\pm$ 21.0 (55)	86.7 $\pm$ 23.1 (40)	91.3 $\pm$ 14.2 (15)

[1]Carapace width at point anterior to 10th lateral spine.

On the dredge, the difference between the average size of sampled crabs ($\bar{x}$ = 81.5 mm) and surface-collected crabs ($\bar{x}$ = 87.9 mm) was significant at the level of $\alpha \leq 0.05$ (Table 3-8). This could be considered supportive of the argument that surface crabs represented a biased sample (see discussion). However, surface crabs had an average size larger than sampled

crabs; for reasons explained below, it was expected that larger crabs would more likely be killed and buried, thus rarely seen among the surface-collected crabs. This group of crabs included one individual of 176 mm carapace width; this crab was alive and unharmed when found. Lacking this individual, the average size of surface crabs would have been 84.4 mm, diminishing or perhaps eliminating the significance of the difference between surface-collected and sampled crabs. Differences between the size of surface crabs and Whitcomb Flats crabs were not tested; it was presumed there would be no significance because the mean size of surface crabs lay between those of the sampled and Whitcomb Flats crabs, whose difference was also non-significant.

Table 3-8. Comparison of crab widths by two-sample "t"-test.

Parameter	Comparison		
	Whitcomb Flats vs. Sampled crabs	Sampled vs. Surface	Sampled alive vs. dead
Pooled variance (s^2_p)	369.5	336.6	245.7
Pooled std. dev. (s_p)	10.6	3.19	3.49
Difference in means	17.3	6.4	9.7
Test statistic (t)	1.63	2.00	2.78
Degrees of freedom (d.f.)	134.	134.	79.
Critical value	1.98	1.98	2.64
Alpha, total	0.05	0.05	0.01
Significance level	None	Yes	High

Within the sampled crabs, a highly significant difference at the 1% level was shown between live crabs ($\bar{x}$ = 76.2 mm) and dead crabs ($\bar{x}$ = 85.9 mm). This was true even though many of the larger dead crabs were collected in pieces too small to be measured. This finding was interpreted to show that larger crabs were more likely to suffer damage or death as a result of dredging.

Survival Experiments

Survival experiments did not provide much useful information, due primarily to lack of adequate aquarium facilities (Table 3-9). Eight crabs from sampling period 2 were kept overnight in a bucket of aerated sea-water at room temperature. Two of these crabs were dead by morning, but the cause of death was uncertain because the aerator pump had failed during the night. Four hours had elapsed between capture of those crabs and re-immersion.

From sampling period 3, all 5 surviving crabs were aerated overnight in the same manner. After 24 hours, one crab had died; autopsy revealed sand in its gill arteries.

All 5 live crabs from sample period 4, plus two larger adults taken from the Westport Boat Basin were placed in a 20-gallon aquarium with a Dyna-Flow filter, after all 7 crabs had been out of water 4-5 hours. One crab with a punctured carapace died during the night and fouled the water; all 6

other crabs died also, probably as a result of poor water quality and low dissolved oxygen.

Of 28 live crabs collected during sampling period 5, 9 were selected for survival experiments due to lack of major injuries. These were placed in a 20-gallon aquarium with Dyna-Flow filter supplemented by an air pump. All 9 survived 24 hours, after which 4 were returned to the Westport Boat Basin.

During sampling period 6, 22 injured and uninjured crabs were collected. Six of these died before being placed in an aquarium. The remaining 16 crabs, plus 3 control crabs of similar size were placed in a flow-through sea-water system at ambient harbor temperatures. After 60 hours, all 19 were still alive. The experimental crabs had been out of water for 5-6 hours before re-immersion.

Table 3-9. Results of survival experiments.

Sample period	Experimental crabs	Control crabs	Survival #	Survival %	Test Length (hr)	Conditions of test
2	8	0	6	75	18	Aerated bucket; pump failure.
3	5	0	4	80	18	Aerated bucket
4	5	2	0	0	24	Recirc. aquarium; fouled water
5	9	0	9	100	24	Recirc. aquarium; minor injuries only
6	22	3	19	73	60	Flow-through at ambient temp.

DISCUSSION

During six days of observation, the SANDSUCKER operated at a rate of 1500 cubic yards per 172 minutes (average) or 8.7 cy/min. When multiplied by total sampling time (53.2 Discharge-minutes), the estimated volume of sediment strained was 463 cy. Therefore, the cumulative entrainment rate was 107 crabs/463 cy, or 0.23 crab/cy. However, this method of estimation provided no confidence intervals, whereas the following method did. Average entrainment (1.94 ± 1.02 crabs/Dm) divided by pumping rate (8.7 cy/min) yielded an estimate of 0.223 crabs/cy, with 95% confidence intervals ranging from 0.106 to 0.340 crabs/cubic yard. During the five months while the SANDSUCKER was operating in Grays Harbor, it removed a total of 770,000 cy of sediment. If it could be assumed that the observed entrainment rate was representative of all mate rial dredged by the SANDSUCKER, the total number of crabs entrained by the dredge during its 1978 period of operation in Grays Harbor could have been 170,940 (range: 81,620 to 261,980). However, this assumption may not be valid (see discussion of data interpretation, below).

Even this range of values cannot be relied upon as "95%" accurate, due to the employment of so many average values. Observed dredge loading times ranged from 140 to 210 minutes, or ±20% of the mean. Faster loading times as a result of greater pumping speed would have resulted in larger estimates of sampled volume, and lower entrainment rates. Capacity of

the loaded barge was not always 1500/cy, but could have been ±10% of that average. Therefore the mean entrainment rate and its confidence intervals could fluctuate from 72% to 132% of the calculated values ($\overline{x}$ = 0.160 to 0.293 crabs/minute ±95% confidence interval). Furthermore, there is no known basis for the assumption that crabs were randomly distributed throughout the entire volume of dredged material; instead they were distributed across the surface of the bottom. However, estimates of bottom surface area affected by all dredges were lacking.

Crabs collected from the surface of the dredged material represent an inherently biased sample. Most of these crabs were probably picked up by the dredge at the end of a load cycle. Thus, they were not deeply buried and could be seen from the surface. Perhaps some of these crabs were picked up earlier by the dredge and buried deeper, but worked their way up through the constantly shifting sediment. Overall, the surface crabs exhibited a much lower proportion of injuries and death than the sampled crabs. Other crabs killed by the dredge would probably have sunk into the sand-water mixture, and therefore would not have been seen or collected by the observers. Some of the surface crabs were smashed when they exited port #2 and hit a splash plate. These would occasionally bounce up onto the catwalk, where they were collected. However, most crabs suffering this fate would have been quickly buried; their proportion is unknown. Of 107 crabs sampled, 17 were collected as portions of bodies (thorax or carapace).

Most of these were listd as "smashed" crabs, but it was apparent that these crabs were killed by the dredge rather than by the sampling procedure. In lieu of other evidence, a conservative estimate of immediate mortality is 45%, the average for sampled and surface-collected crabs; it was concluded that the mortality of sampled crabs was artificially increased, but that the mortality of surface-collected crabs was too low because of biased sampling.

Precise conclusions cannot be made from the results of survival experiments. It is unclear to what degree mortality was influenced by poor water quality and low dissolved oxygen. The potential seriousness of many injuries may have been increased by long periods of time out of water. Considering only sample periods 3 and 6, after which 7 of 27 live crabs died, a speculative estimate of post-dredging mortality would be 26%, thus reducing the immediate survival rate from 55% to 41%. Crabs which survived the dredging faced further danger of possible suffocation under tons of sand. Although it could not be estimated, it is presumed that such an effect would decrease the survival rate even more.

Questions have been raised concerning the application of reported crab catch rates to expanded dredging efforts. These catch rates are strictly applicable only to the season and location in which they were determined. There exists the possibility that differences in catch rate could occur if there are temporal or spatial fluctuations in crab population

densities within Grays Harbor, especially in the ship channel. Crab distribution studies are currently underway to explore these possibilities.

There are also questions concerning the immediate impact and the long-term impact of dredging efforts. Examination of Table 3-3 reveals low catch rates (C/Dm) on two of three sampling dates in November, 1978 (periods 1 and 3). At that time, the SANDSUCKER was working in an area that had been extensively dredged before sampling began. Those samples could be considered as representative of maintenance or late-stage dredging. In December, 1978, the SANDSUCKER operated over an area that had not been dredged for about one year. Sampling was conducted on 3 days during the first two weeks of dredging at this location. Catch rates were high (2.00 C/Dm) on 2 of those days and low (0.68 C/Dm) on one. Higher catch rates may be indicative of an "initial impact" phenomenon, i.e., more crabs (or other organisms) may be captured during the early stages of dredging than during the later stages. However, closer examination revealed that the average catch rate of sample periods 1-3 (1.89 C/Dm) was equal to the catch rate for periods 4-5 (1.89 C/Dm). Although not statistically compared, such equality seemed to justify combining samples taken from both areas for purposes of calculation, and that the combined data represented average conditions for autumn maintenance dredging in the outer harbor.

It is still a possibility that sample 2 (11/10/78) represented a "hump" in the channel, i.e., a small area missed by incomplete early dredging. Such humps may increase sample variation and hinder interpretation of data; they may also contribute to early recolonization of the dredged area (Slotta et al., 1973). Although differences in crab mortality rates may have occurred between early and later dredging, they were quantifiable in this study. It is suggested that this possibility be considered before extrapolation of the reported data to other seasons and locations, and that the crab catch rates may show a decline after the initial impact, as dredging continues.

As was mentioned earlier, sudden changes in bottom topography or incoming swells would occasionally lift the dredge suction head from the channel bottom. These occasions were not included in sample times recorded, but are included in pumping time. Accurate records of these occasions were not made, often because the work party was not on board the dredge throughout the entire loading cycle. Therefore, pump times may be overestimated by 3-6%. Although catch rates (C/Dm) would not be affected by this discrepancy, mortality rates per hopper load could be reduced by 3-6% of the estimates if this phenomenon occurred regularly.

The least precise factors in the analysis were probably the estimates of the proportion of discharged material which actually passed through the sampling baskets ("% flow"). This

proportion was estimated in steps of 5%, usually being between 70 and 90%. The accuracy of these estimates is questionable, but since they were all made by the same person, some amount of consistency was involved. Inherent error probably amounted to ±5%. Estimates of the amount of total discharge from each hole were also of questionable accuracy. However, these produced little overall error; results obtained using these values (Method 1) were not significantly different from results obtained using the average discharge rate (Method 2).

SUMMARY

1. During 6 days of sampling, 90 whole crabs and major portions of 17 others were collected from an estimated 463 cubic yards (cy) of dredged sediment. Fifty-five other crabs were collected directly from the surface of the sediment in the hopper.

2. Average entrainment rate was 1.94 ± 1.02 crabs per minute of pumping, or 0.223 ± 0.116 crabs/cy of sediment ($\bar{x}$ ± 95% confidence interval).

3. The immediate mortality rate among sampled crabs was 61%; among surface-collected crabs it was 30%. The true value probably lies between these two, at about 45%.

4. Injuries resulting in delayed death may increase the dredging-related mortality rate to about 59%.

5. An average hopper load, requiring 172 minutes of pumping, may contain 334 crabs (158 to 509), of which 167 to 210 might die as a result of dredging.

6. Sand in the gill arteries and/or lamellae was associated with the deaths of most crabs autopsied.

7. The average width of entrained crabs (81.5 mm) was not significantly different from that of crabs trapped on nearby Whitcomb Flats (98.9 mm) due to a high degree of variability within the latter sample.

8. Difference between the average width of sampled crabs (81.5 mm) and crabs collected from the surface of sediments in the hopper (87.9 mm) was significant at $\alpha < 0.05$.

9. Crabs which survived entrainment and recovery were significantly smaller than those that died (76.2 vs. 85.9 mm, $\alpha < 0.01$).

10. No significant difference was found between results produced by two different methods of data analysis.

11. Extrapolation to expanded dredging efforts is hindered by the occurrence of great spatial and temporal variation in crab population densities.

SECTION 4

SAMPLING ABOARD THE HOPPER DREDGE PACIFIC

The dredge PACIFIC, owned by the U.S. Army Corps of Engineers (USACE), is a self-propelled hopper dredge which normally carries a crew of 15. Constructed in 1937, the PACIFIC is the smallest hopper dredge in the USACE Westcoast fleet. It is propelled by two 600 hp diesel engines, and has an overall length of 54.9 m (180 ft). The PACIFIC employs two 46 cm (18 in) dia. drag arms, each with a suction head approximately 122 cm (4 ft) wide. Sediment entering the two arms converges into a single pump operating at about 210 rpm, and is then discharged into the hopper via a single discharge opening. The hopper, divided into 4 bins, has a capacity of 500 cubic yards (cy), and requires 30-60 minutes to fill. Sediment is distributed among the 4 bins by a splash plate below the discharge opening.

The PACIFIC has a sidecasting device, shaped like a large "T". Closure of the main valve of the discharge pipe redirected sediment flow into the base of the "T". The slurry may then be sidecast from one or both arms of the sidecaster by opening valves on either arm of the "T".

METHODS AND MATERIALS

Sampling was conducted aboard the hopper dredge PACIFIC on March 11, 19, 20, 21, and 22, 1979. A variety of techniques

were tested, in an attempt to find the best sampling method. The main discharge opening into the hopper was almost completely enclosed, and had a splash plate positioned about 30 cm (1 ft) below it. Most of the hopper was covered by deck plating, and contained numerous baffles, inhibiting access to, as well as observation of, the hopper contents. Therefore, the sidecaster appeared to offer the best opportunity for sampling the discharge.

The sidecaster arms (sidearms) projected laterally from amidship, ending even with the hull, about 4 m (13 ft) above deck level. A 46 cm (18 inch) dia., 90° elbow was welded to the starboard sidearm to direct the discharge straight down towards the water. Utilizing this modified sidearm, 3 methods of crab collection were assessed.

1) <u>Canvas chute and basket</u>. A cylindrical canvas chute was attached to the elbow on the starboard sidearm. Steel hoops were sewn in at 1 m intervals, to help maintain the cylindrical shape. This chute extended a few inches beyond the gunwhale at deck level. Beneath the chute opening a large steel basket was suspended such that the basket bottom was submerged 15-30 cm (6-12 inches) below water. The basket measured 76 cm x 76 cm x 61 cm (30 inch x 30 inch x 24 inch) with diamond-shaped mesh 16 mm x 38 mm (5/8 inch x 1 1/4 inch), and could be raised or lowered by an electric hoist.

On March 11, 1978, with the chute and basket in place, dredging was attempted with the starboard sidearm valve open

and the main discharge valve partially closed. In this manner, a small portion of total sediment flow (15-25%) was diverted through the chute-basket arrangement. Two sample runs of several minutes were made, but the sediment load was too great for the chute, causing the hoops to collapse and the chute to tear during the second run. The chute was re-sewn on board, and two more short runs were made. At this time, the main discharge valve malfunctioned, so sampling was discontinued.

2) Steel pipe and basket. On March 19, a 46 cm dia. (18 inch) steel pipe was welded to the elbow on the sidearm. This pipe discharged sediment at a point about 30 cm (1 ft) beyond and below deck level. The steel basket was suspended from padeyes on the pipe, and sampling continued. To prevent further malfunctions, possibly caused by sediment accumulating in the main valve, the valve was closed completely, shunting 100% of the discharge into the diverter. With both sidearms open, approximately 95% passed through the starboard arm and hence into the basket. With this arrangement, 5 sample runs were made, averaging 8 minutes each.

3) Steel pipe and net. To alleviate the problems of splashing, and smashing of crabs against the steel basket, a small trawl net was tied around the mouth of the modified discharge pipe. Net A was 1.8 m (6 ft) long, #24 twine, and 2.0 cm (3/4 inch) mesh knot-to-knot (kt-kt). It was used for two sampling runs on 3/19/79, and once more on 3/20/79, until it became irreparably torn. A second net was obtained and used

for three sampling runs on 3/21/79. Net B was the "cod-end" of a commercial shrimp trawl, about 4.6 m long (15 ft), #48 twine, 2.0 cm (3/4 inch) kt-kt. It, too, was irreparably torn, and replaced by Net C, which was 2.4 m long (8 ft), #32 twine, 2.0 cm (3/4 inch) kt-kt. Net C lasted through two samples on 3/21/79, and 8 more on 3/22/79 at which time sampling aboard the PACIFIC was completed.

In operation, these nets were almost completely submerged (except where tied around the discharge pipe) and trailed back from the pipe as the dredge traveled. Thus, sediment entering the net passed directly down through the webbing, whereas crabs, sticks, and other debris collected at the end of the net where they were not directly in the path of material exiting the pipe. When full, the nets were lifted by attaching both ends to the electric hoist.

On March 11, 19, and 20, all sampling runs were made in the same vicinity, between buoys "15" and "15A". This location was selected because the PACIFIC was in the process of dredging this area to deepen the ship channel. On March 21 and 22, seven other locations were sampled, upriver to buoy "44" in the Hoquiam River Reach. All samples were taken within the confines of the channel boundaries. Two samples attempted about 100 m north of the channel near buoy "15A" contained heavy gravel which destroyed nets A and B.

Examination of Collected Material

When full, nets were emptied onto the deck. There, workers sorted out living material, then replaced the net for further sampling while the collected organisms were examined and recorded. Crabs were measured and sexed; live ones were retained for placement in an aquarium on shore. Crabs were defined as partial, if missing the carapace, thorax, or parts of either, or whole, if missing only legs. Damage to each crab was categorized according to number of legs damaged, and degree of damage to carapace. Legs broken below the autotomy plate were considered equivalent to those autotomized. Categories were not exclusive, i.e., a single crab may have been listed in several categories, except for "No damage" and "Smashed" which were exclusive. Dead crabs were examined for the presence of sand in their gill arteries. Individual records were maintained for each crab.

All crab parts were examined for the presence of fresh tissue; parts without attached tissue were considered as molted exuviae. Partial crabs (smashed) with carapace and thorax intact were counted as individual crabs. The number of thorax-only portions was counted, as was the number of carapace-only portions with eye-stalks or sockets; of these two groups, the one of greater abundance was considered to represent the number of crabs whose carapace and thorax had been separated. This number was added to the number of partial crabs with carapace-thorax connected, and the number of whole

crabs (live, dead and moribund) to obtain the total number of crabs collected per sample. Organisms other than crabs were identified to lowest taxon possible, counted, and discarded.

Generally, material from different samples was kept separate, except for runs made on 3/11/79, and some runs made on 3/19/79, all of which were made in the same location (buoys "15" - "15A").

As mentioned above, the design of the PACIFIC limited access to the hopper. During sampling, no material was being deposited in the hopper. For these reasons, no crabs could be systematically collected from the hopper, although some crabs were observed in the hopper occasionally. Thus, no comparison could be made between mortality of crabs in the hopper (dredge-induced) and mortality of crabs in the samples (dredge and sampling-induced).

Survival Studies

All live crabs, and most moribund crabs were returned to shore in an open bucket without water. There, they were placed into one of four 60-gallon flow-through seawater aquaria. Water temperature approximated that of surface water in Grays Harbor. Daily observations were made of crabs and water temperature. Any dead crabs were identified, and this information recorded along with time out of water, and length of time in aquarium. Surviving crabs were fed herring or smelt every

other day. Crabs surviving 4-5 days were returned to the harbor.

Control crabs were collected by ring net from the Westport Marina. These crabs were measured and sexed, then subjected to one of two treatments: 1) "Tank control" crabs were placed into the aquarium after examination, within 30 minutes of capture. 2) "Exposed" crabs remained in a shaded dry bucket at atmospheric temperature 4-6 hrs before placement in the aquarium, to simulate the effects of exposure on crabs returned to shore from the dredge. Several exposure mortality experiments were done, some concurrent with dredge survival studies but in separate tanks, and some when no dredge studies were in progress.

Data Analysis

Total amount of sediment sampled was calculated on the basis of discharge minutes (Dm) as described previously for the SANDSUCKER (see Section 3).

Dm = (sample time) x (% flow) x (% discharge), where

sample time = time recorded while net/basket received discharge,

% flow = proportion of all entrained material exiting the starboard sidearm

% discharge = proportion of discharged material that actually passed through basket/net.

A factor of 8.49 cy/Dm was used to convert discharge minutes to volume sampled. This factor was the overall average rate of sediment pumping by the PACIFIC during its two-week stay in Grays Harbor in March, 1979.

Total crabs collected were then divided by discharge minutes (Dm) or volume sampled (cy) to obtain estimates of the crab entrainment rate in terms of crabs/minute of dredging or crabs/cubic yard of dredged sediment. Results of each sample were computed, and weighted averages were calculated separately for each sampling location.

RESULTS

Sampling aboard the PACIFIC was conducted at eight different locations, designated by the nearest channel buoy (Figure 1, Table 4-1). A total of 163 crabs were recovered from approximately 1,058 cy of material strained. Crabs were not evenly distributed throughout this material - 42% were recovered from one area (buoys "15" - "15A") where 52% of sampling effort was expended. No crabs were recovered from 3 stations (buoys "28", "34" - "36", and "44") where 15% of sampling effort was expended, and one station ("16") produced 29% of recovered crabs with only 7% of sampling effort. These differences are discussed below.

Table 4-1. Crab entrainment on PACIFIC, by sampling area.

Sampling location (Buoy no.)	# Samples	# Crabs	Time in Discharge minutes (Dm)	Vol in cubic yards (cy)	Crabs/Dm	Crabs/cy
"15" to "15A"	12	69	64.6	548.4	1.07	0.126
Near "15A"	2	27	15.0	127.4	1.80	0.212
Near "16", S. side	1	47	9.0	76.4	5.20	0.615
Near "18", S. side	1	2	6.0	50.9	0.33	0.039
"21" to "SC", S. side	1	3	5.0	42.5	0.60	0.071
"21" to "SC",N. side	1	15	6.0	50.9	2.50	0.295
"28" to "30"	2	0	6.0	51.0	0.0	0.0
"34" to "36"	1	0	7.5	63.7	0.0	0.0
Near "44", S. side	2	0	5.5	46.7	0.0	0.0
Combined Total	23	163	124.6	1,058	1.31	0.154

During sampling with the canvas chute-basket arrangement, percent flow was only about 20% of entrained material (visual estimate), as a result of the main valve remaining partially open. When sampling with steel pipe and basket system, the main valve was closed completely, and both sidearms opened fully. This allowed about 5% to escape through the port sidearm. The great difference in flow rate between the two arms was apparently due to an effect of siphoning by the steel pipe, which discharged about 30 cm (1 ft) above water level. Additionally, an estimated 5% of the discharge splashed out over the basket rim. To decrease the error in these visual estimations, the port sidearm valve was closed, and a net tied

around the base of the steel pipe. This arrangement resulted in 100% discharge and 100% flow passing through the net.

Dramatic differences in sediment quality were encountered at the different sampling sites. Area "15" - "15A" consisted of clean brown sand, shells, and sticks. Several attempts were made to sample an area about 100 m N of "15A", outside the ship channel. Much heavy gravel was encountered there, which resulted in the destruction of two of the nets used (A and B). Therefore, further dredge sampling was confined within the channel margins. Areas "15A", "16" and "18" were characterized by a sediment consistency similar to that of "15" - "15A". Muddy silt and small sticks were encountered at "21", "28" and "34" - "36". The latter two stations produced no crabs. Near buoy "44" the net became rapidly clogged with muddy debris including a large quantity of decaying leaves. At one point (near "36") the drag head became so bogged down in silty mud that very little solid matter was entrained for 12 minutes.

Dredge personnel explained that, in such soft sediment, the drag head sinks into the mud and plows up the bottom, reducing intake, and possibly disturbing the sediment ahead of it. This action might scare or push away any crabs present. Such an effect could partially account for the absence of crabs in samples taken at the three upriver stations where silty mud was observed. It is believed that crab catch rates observed at the other sampling stations reflected, reasonably well, the relative population densities of crabs in those areas.

Crab Entrainment

Differences in crab catch rate were also apparent among stations. At those 6 locations where crabs were recovered, entrainment ranged from 0.039 crabs/cy ("18, S. side) to 0.615 crabs/cy ("16"), or 0.33 to 5.20 crabs/minute, respectively. (Table 4-1). This fifteen-fold difference is dramatized by the proximity of the two stations exhibiting those extreme values - both were situated along the north side of Whitcomb Flats, barely 650 m apart. The remaining 3 stations were considered abnormal in that no crabs were recovered from sample volumes similar to the first 6. The weighted average catch over the 6 stations included above was 0.182 crabs/cy; overall average, including the three stations where no crabs were recovered, was 0.154 crabs/cy. These values were calculated on a weighted or cumulative basis (total # crabs / total volume dredged). Confidence limits could only be obtained when entrainment rates for each area were used as individual observations. In that case the average entrainment rate was 0.226 $\pm$ 0.223 crabs/cy when the six non-zero values were used, or 0.151 $\pm$ 0.156 when all nine stations were included ($\bar{x}$ $\pm$ 95% confidence interval).

Crab Damage

Of all 163 crabs recovered from the PACIFIC, 67% were dead, 33% were alive, and 34% of the live crabs were moribund (close to death - Table 4-2). At the time of examination of crabs on board the dredge, the proportion of whole, live, dead,

and smashed crabs was as shown in Figure 4. Of all crabs, 62% were whole (as previously defined, including all live crabs) whereas 38% were smashed into numerous fragments. Smashing appeared to account for 62 of 110 deaths (56%).

Table 4-2. Condition of all crabs recovered from PACIFIC; by sampling method.

	Number			%		
Origin[1]	B	N	C	B	N	C
Total recovered	22	141	163	100	100	100
Whole	10	91	101	59	65	62
Smashed/partial	12	50	62	41	35	38
Alive	6	47	53	27	33	33
Avg. size in mm.(n)	89.9	96.3	95.5	(7)	(47)	(54)
Moribund[2]	3	15	18	50	32	34
Dead	17	94	110	73	67	67
Avg. size in mm.(n)	128.7	97.4	99.3	(4)	(61)	(65)
Males	7	76	83	32	54	51
Females	4	30	34	18	21	21
Unknown sex	11	35	46	50	25	28
M/F ratio	1.75	2.92	2.77	-	-	-
Autopsied	6	61	67	-	-	-
Sand in gills[3]	5	44	49	83	72	73

[1]B=Basket, N=Net, C=Combined
[2]Moribund expressed as % of live crabs
[3]% of those autopsied, only

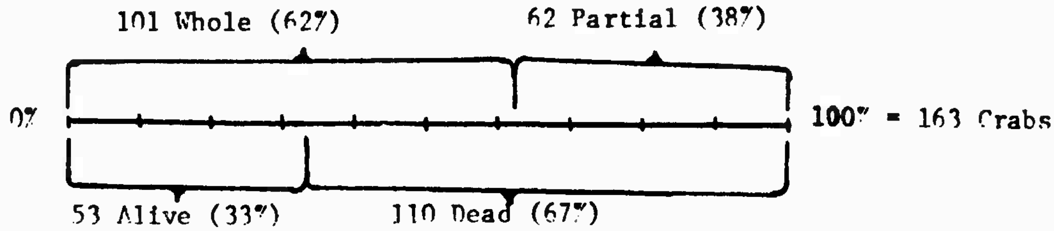


Figure 4. Proportions of whole, partial, live and dead crabs recovered from PACIFIC.

Of whole crabs examined, only 5% escaped damage entirely (these retrieved only from nets; Table 4-3). Legs were lost by 89% of whole crabs; the average number of legs lost or damaged was 4.6. Breaks in the coxae or bases (leg segments proximal to the autotomy plate) were sustained by 62% of whole crabs (such breaks may have been the location where sand entered the hemocoel - see below). Many crabs (42%) sustained small punctures or hairline cracks in their exoskeletons, though many of these were not fatal. Loss of the abdomen (by 27% of whole crabs) was associated with the death of the crab in all but one case. Twenty percent of whole crabs died as a result of major damage other than smashing (large holes, loss of all legs, major cracks). Of 67 whole crabs autopsied (including some moribund crabs), 73% had sand in their gill arteries (Table 4-2).

Sex frequencies for all crabs were 51% males, 21% females, and 28% unknown. Overall sex ratio was 2.77 males/females.

Table 4-3. Condition of whole crabs recovered from PACIFIC

Condition[1]	Number B	Number N	Number C	% B	% N	% C
Whole crabs	10	91	101	59	65	62
Missing 1-2 legs	4	23	27	40	25	27
Missing 2 legs	3	60	63	30	66	62
Avg. # legs damaged	2.9	4.8	4.6	-	-	-
Broken coxae or bases	6	57	63	60	63	62
Small cracks/punctures	7	35	42	70	40	42
Lost abdomen	1	26	27	10	29	27
Major damage	4	16	20	40	18	20
No damage	0	5	5	0	5	5

[1]B=Basket, N=Net, C=Combined

Basket-sampled crabs experienced a slightly greater mortality than the net-sampled crabs (73% vs. 67%; Table 4-2). However, no great reliability can be attributed to basket vs. net comparisons because of the disparity in sample sizes - basket samples accounted for 17.6 discharge minutes, or only 14% of total sampling effort. Major damage was more prevalent among basket-sampled crabs. The baskets were situated such that crabs exiting the discharge pipe traveled only about 30 cm (1 ft) before hitting the basket bottom, which they did with considerable force, even though the basket was partially submerged. Certain types of injuries were more likely to occur in the basket than in the nets. In baskets, more crabs were smashed (41% vs. 35% nets; Table 4-2), sustained major damage

(40% vs. 18% of whole crabs; Table 4-3), or had cracks and punctures in the exoskeleton (70% vs. 40% of whole crabs; Table 4-3). This discrepancy was probably the result of violent impact of crabs against the basket bottom. In the nets, however, more crabs lost legs (91% vs. 70% of whole crabs), or abdomens (29% vs. 10% of whole crabs; Table 15). The increase in injuries of this kind was probably the result of tangling in the net as the crabs were expelled from the discharge pipe. Only the proportion of crabs with broken coxae or bases was approximately equal between the two groups (60% baskets vs. 63% nets, whole crabs; Table 4-3). As mentioned above, these figures must be viewed cautiously due to the difference in sample sizes.

Damage comparisons were also made between live and dead crabs (Table 4-4). This analysis was made after completion of survival tests, so the number of dead crabs includes 24 that either died during survival tests, or were autopsied and discarded as moribund. All dead crabs had suffered loss of legs, averaging 6.0 lost or damaged legs per crab. Of those crabs surviving, 72% lost legs, averaging only 1.4 lost or damaged legs per crab. Cracks in the coxae or basis were present among 80% of dead crabs ($\bar{x}$ = 2.9 per crab), but only 28% of live crabs ($\bar{x}$ = 0.4 per crab). Cracks and punctures of the exoskeleton were observed in 52% of dead crabs, but only 28% of live crabs. Abdomens were missing from 40% of dead crabs, but only 3% of live crabs. No crabs survived other

types of major damage (large holes or cracks in shell, or separation of thorax and carapace). Live crabs averaged 86.5 mm (n = 29), whereas dead crabs averaged 104.7 mm (n = 65). When compared by two-sample "t"-test, this difference was found to be significant at a level of probability between 0.02 and 0.01 (Table 4-5). This result indicates that smaller crabs were significantly less likely to sustain fatal injuries as a result of dredge entrainment.

Table 4-4. Comparison of damage between live and dead crabs from PACIFIC.

Condition	Alive #	Alive %	Dead #	Dead #
Number examined[1]	29	100	65	100
Avg. size (mm)	86.5		104.7	
# with lost or damaged legs	21	72	65	100
Avg. # legs damaged/crab	1.4		6.0	
# with broken coxae/bases	8	28	52	80
Avg. # breaks/crab	0.4		2.9	
# with small cracks/punctures	8	28	34	52
# missing abdomen	1	3	26	40
# with other major damage	0	0	16	25

[1]Dead crabs include 24 that were recovered alive but died later.

Table 4-5. Two sample "t"-test between widths of live and dead crabs recovered from PACIFIC.

	Alive	Dead
Mean, in mm	86.5	104.7
n	29	65
Standard deviation	26.8	32.0

	Alive vs. Dead
Pooled variance (s_p^2)	930.6
Pooled std. dev. (s_p)	6.91
Difference in means	18.2
Test statistic (t)	2.632
Degrees of freedom (d.f.)	92
Critical value	2.373
Alpha, total	0.02
Significance level	yes

Other organisms collected are listed in Table 4-6. The most common incidental species were sand lance (*Ammodytes hexaptera*), sand shrimp (*Crangon spp*), staghorn sculpin (*Leptocottus armatus*), and the bent-nose clam (*Macoma nasuta*). While *L. armatus* and *Crangon spp* were more or less evenly distributed, most of the sand lance were recovered from the outer harbor (near buoys "15" - "15A") and most of the clams from near buoy "28".

Table 4-6. Numbers of individuals of other species in PACIFIC samples.

Organism	Station (Navigational buoy no.) 15-15A	15A	16	18	21	28	34	44	Total
Staghorn sculpin (*L. armatus*)	9	6	2	2	9				28
Sandlance (*A. hexaptera*)	23	18		1		2			44
Pipefish (*Syngnathus leptorhynchus*)	5	1			1				7
Starry flounder (*Platichthys stellatus*)	1								1
Sand sole (*Psettichthys melanostictus*)	4	4	4		2				14
Sanddab (*Citharichthys sordidus*)	3	1	1		2				7
Tomcod (*Microgradus proximus*)	1								1
Snailfish (*Liparidae*)					1				1
Smelt (*Osmeridae*)								1	1
Sand shrimp (*Crangon spp*)	9	12	1	1	4	4		3	34
Bent-nose clam (*Macoma nasuta*)					2	20	1		23
Piddock clam (*Zirphaea pilsbryi*)						1			1
Heart cockle (*Clinocardium nuttalii*)	1					1	1		3
Polychaete worm (*Nephtys caeca*)	3								3
Polychaete worm (*Ophelia limacina*)	1								1
Polychaete worm (*Unknown species*)								2	2

Note: Polychaetes were rarely retained by the large mesh of nets (1.9 cm square) or baskets (1.6 x 3.8 cm).

Crab Survival

Fifty live or moribund crabs collected from the PACIFIC were retained for placement in the flow-thru aquarium. Fifteen of these crabs died during the time between recovery and placement in the tanks (3-6 hr; Table 4-7). Two more died within the next 48 hr. Therefore, the overall delayed mortality for dredge-recovered crabs was 17/50 or 34%.

Four control experiments were run, during which experimental crabs remained out of water (were "exposed") for 3.5, 4.5, 5.5 hr (Table 4-7). Of 39 "exposed" crabs 5 died during exposure and 1 died between 24-48 hr later, for an overall exposure mortality of 15%. Mortality tended to increase with exposure time, from 8% (3.5 hr) to 20% (4.5 hr) to 22.5% (5.5 hr; average of two tests with results of 8% and 37% respectively). No deaths were observed among the 35 "tank-control" crabs, i.e., crabs placed directly into the aquarium after capture. These crabs were out of water no more than 15 to 30 minutes. These tests were run concurrently with "exposure" tests.

In view of this evidence, the observed post-dredging mortality of 34% may have included an exposure-induced mortality of 15%. Therefore, the remaining 19% mortality was probably the result of injuries or stress caused by dredge entrainment.

The average size of the 26 dredge-recovered crabs that survived (86.3 mm) was smaller than the average size of the 24 that died during or from exposure (109.3 mm). This difference

Table 4-7. Results of crab survival experiments.

Origin of crabs	Crabs N	Crabs Avg. size	Crabs ET[1] (hr)	Survival (%) To tank	Survival (%) 24 hour	Survival (%) 48 hour	Survival (%) 96 hour
Dredge "PACIFIC" (net)	44	97.5	3-6	70	70	66	66
(Basket)	6	95.8	3-4				
Controls (3/10) tank	8	89.0	0.5	100	100	100	100
exposed	12	*	5.5	92	92	92	92
Controls (5/11) tank	8	100.3	0.5	100	100	100	100
exposed	5	94.4	4.5	80	80	80	80
Controls (5/13) tank	6	94.3	0.5	100	100	100	100
exposed	8	91.0	5.5	63	63	63	63
Controls (5/20) tank	13	112.0	0.5	100	100	100	*
exposed	12	113.6	3.5	100	100	100	*

*Data lacking or incomplete.
[1]ET = exposure time (out of water).

in sizes (22.9 mm) was highly significant at the level of $p = 0.01$, when compared by two-sample "t"-test (Table 4-8). However, neither of these groups ("survived" or "died") was significantly different from the average size of all crabs retained for survival studies (97.3 mm). These crabs represented a large subsample of the crabs compared in Table 4-5, which may explain the similarity between average sizes shown in Tables 4-5 and 4-8.

Table 4.8. Two sample "t"-test between widths of crabs used for PACIFIC survival studies.

Parameter	All	Survived	Died
Mean	97.3	86.3	109.2
n	50	26	24
Standard deviation	31.1	28.3	30.0
	All vs. survived	All vs. died	Died vs. survived
Pooled variance (s^2_p)	910.5	945.0	849.2
Pooled std. dev. (s_p)	7.30	7.63	8.25
Difference in means	11.0	11.9	22.9
Test statistic (t)	1.51	1.56	2.78
Degrees of freedom (d.f.)	74	72	48
Critical value	1.668	0.10	0.01
Significance level	None	None	High

DISCUSSION

Observed rates of crab entrainment aboard the PACIFIC varied from 0.0 to 0.615 crabs/cy. The average entrainment from all nine stations was 0.154 crabs/cy. Although no crabs were collected while dredging at the 3 easternmost stations, monthly crab sampling (see Section 7) has shown that crabs occur abundantly in those areas. Therefore, it is believed that low crab entrainment at those stations was directly attributable to the altered action of the drag head in soft sediments. Based on this suspicion, a more accurate statement is that the average entrainment from 6 sandy bottom areas (all within the South Reach) was 0.182 crabs/cy, and that entrainment from

mud-silt sediments (Crossover and North Channels) was not detected (0.0 crabs/cy) under maintenance dredging conditions.

Sampled crabs sustained 67% immediate mortality. Presumably a portion of this was induced by the sampling procedures. Unfortunately, no crabs could be collected from the hopper for comparison of damage. However, sampling conditions were not greatly different from conditions present in the hopper, i.e., entrained crabs smashing against the splash plate when being discharged into the hopper probably suffered damage comparable to that exhibited by crabs collected in sampling baskets and nets. These two fates seem very comparable from a qualitative viewpoint, and could also be quantitatively comparable. Therefore, it is reaonable to assume that the mortality observed among sampled crabs represented the mortality caused by discharge of crabs into the hopper. As shown by survival experiments, a certain proportion of those crabs that survive entrainment (herein estimated to be 19%) suffer delayed mortality, probably as a result of injuries and stress, thereby increasing the total dredging related crab mortality to an estimated 73%.

While dredging in the South Reach Channel during March, 1979, the PACIFIC removed 58,000 cy of sediment. If it can be assumed that the average entrainment rate of 0.182 crab/cy was representative of the entrainment in this portion of the channel, it is possible that 10,556 crabs were entrained during that operation, of which perhaps 73%, or 7,706 crabs died.

Alternatively, if the estimate of 0.226 crabs/cy is utilized, then 13,108 crabs may have been entrained (range 174 to 26,042) of which perhaps 9,568 were killed. Since one location (buoys "15" - "15A") accounted for 52% of the total sampling effort, it is more justified in this case to utilize the former smaller average of 0.182 crabs/cy, because this value is weighted, i.e., it takes sample size into account, whereas the non-weighted average assumes an equal weight (i.e. sample size) for each individual observation.

Comparisons between crabs recovered alive and dead, and those used in survival studies confirmed that smaller crabs were less likely to sustain injury and/or death.

The accuracy of visual estimates of "% discharge" and "% flow" may have been about ±50% for samples taken via the canvas chute-basket system, improving to about ±10% with the steel pipe-basket arrangement. These two sampling methods accounted for only 2.6 and 11.5% of total sampling time, respectively, so their combined imprecision only adds an error of about ±2.5% ((.50 x .026) + (.10 x .115)). This is considerably less than the natural variability inherent in the sampling procedure. When the basket was replaced by nets, and the port sidearm closed, 100% of entrained material was sampled, so no visual estimates were required.

Admittedly, sample sizes at the upriver stations were small (5-9 minutes at station "16" through "44"). Results should be viewed with that caution in mind. Longer sampling

times and/or different seasons might have produced different results.

Conversion of crab entrainment rates to a crab per volume basis required the use of a conversion factor (8.5 cy/min). This factor, the total volume dredged during total operation time in Grays Harbor, was obtained from the log of the PACIFIC. For purposes of calculation, the assumption was made that the rate of dredging (cy/min) during experimental sampling was identical to that during regular dredging time, while the scientific party was not on board. Most such dredging was accomplished in that section of the channel between buoys "15" and "16", where most of the experimental sampling was also done. This assumption has been supported by USACE personnel. If, however, the dredging rate was actually less during test sampling, the volume sampled would also have been less than estimated, thus the actual entrainment rate would have been greater than reported here. Conversely, if the dredging rate had been greater than normal, and more volume sampled than estimated, the actual entrainment would have been less than that reported here.

SUMMARY

1. During 5 days of crab sampling aboard the hopper dredge PACIFIC, 163 crabs (whole and partial) were recovered from 1,058 cy of material representing 124.6 minutes of dredging.

2. At nine different sites sampled, entrainment rates varied from 0.0 to 0.165 crabs/cy, or from 0.0 to 5.20 crabs/min.

3. The best estimate of average entrainment from sandy bottoms was 0.182 crabs/cy. This estimate is a weighted average including only those six sampling stations within the South Reach. Entrainment from three sites with mud-silt bottoms was 0.0 crabs/cy.

4. Averaging of individual rates for the six South Reach sites produced an estimate of 0.226 ± 0.223 crabs/cy ($\bar{x}$ ± 95% confidence interval). This estimate is probably less accurate, as it does not account for the difference in sampled volumes, but it does provide confidence intervals.

5. Zero crab recovery in the Crossover and North Channels was believed to be the result of altered action of the drag head in soft sediment. If this phenomenon occurs regularly, the result will be low crab entrainment by hopper dredges in those parts of the channel.

6. Immediate mortality of sampled crabs was 67%. Although it could not be measured directly, mortality in the hopper was concluded to be of comparable magnitude due to the similarity between sampling and entrainment conditions.

7. Delayed mortality, as a result of injury or stress (but not exposure) accounted for an additional 19% of those crabs surviving entrainment and recovery.

8. Surviving crabs were significantly smaller than crabs which suffered immediate or delayed death.

SECTION 5

SAMPLING DISCHARGE OF THE PIPELINE DREDGE MALAMUTE IN WESTPORT AND ABERDEEN

The pipeline dredge MALAMUTE consists of a non-propelled floating barge 30.5 x 21.2 m (100 x 40 ft), housing a 41 cm (16 inch) diameter electric suction pump, plus winches and cables for the operation of the drag head. The suction head, extending forward from the bow, is surrounded by a 1.5 m (5 ft) diameter cutting head, shaped like an egg beater, which rotates at about 200 rpm while in operation. The dredge is made partially immobile by placement of a removable piling at one corner of the stern. Using this piling as a pivot, winches are employed to pull the bow from side to side via the dredges anchor cables. In this manner, the cutter head may swing in an arc of 50-60 m (164-197 ft). A strip of sediment 1.5 m (5 ft) in width is removed during each swing, which requires about 3 minutes. Upon reaching the desired depth, the dredge is stepped forward 1-2 m. The suction pump operates at approximately 450 rpm, and can pump about 40,000 liters per minute (10,600 gal. per min.), creating an internal pressure of 5.30 kg/cm (75 psi).

Rather than being dumped onto a barge, dredged sediment was pumped through a 46 cm (18 inch) diameter pipeline into an enclosed, upland disposal site. The length of this pipeline

varied from 100 to 1,500 m (330 to 4,920 ft), depending on the distance from the dredge to the disposal area.

METHODS AND MATERIALS

Pipeline dredging occurred in the Westport boat basin from September 22 to November 17, 1979. Sampling took place there on September 22 and 29, October 6, 10, and 31, and November 10, 1979. Dredging occurred at the Port of Grays Harbor (PGH) Terminal Number 4 (T-4) in Aberdeen, from November 27 to December 13, 1979, and sampling was conducted on December 11 and 12.

Pipeline Sampling

In order to strain the discharged sediment for crabs and other animals, a large steel basket was placed under the discharge end of the pipeline and held in place by a forklift or backhoe. This basket was 91 x 76 x 122 cm (36 x 30 x 48 inches). A U-shaped slot was cut into one end of the basket to accommodate the insertion of the 46 cm dia. pipe. In practice, the basket was maneuvered into the pipe, which was allowed to extend 5-15 cm (2-6 inches) inside the basket. This procedure was often very difficult due to the volume and force exerted by the discharged material, and instability of the sediment on which the backhoe operated. The basket remained in place until partially full with gravel and debris, which took from 1-15

minutes. It was then removed and emptied, and its contents sorted for organisms or parts thereof.

Examination of Collected Material

Crabs collected in the basket were measured, sexed, and categorized as alive or dead, and within the latter category, whole or partial. Whole crabs were defined as those with thorax and carapace intact, though perhaps missing some legs. Partial crabs were defined as those of which only separated thorax or carapace portions were found, or crabs which were cut vertically in two. Moribund crabs, those exhibiting only faint signs of life, were defined as dead (previous experiments had shown that almost all crabs in this state failed to survive upon return to water). Partial crabs were examined for the presence of fresh tissue; if absent, the crab or part was declared to be a cast exuvia. On the occasion when only fresh legs were found in a basket load, these were counted as one dead crab.

Occasionally, live and dead crabs were collected by hand from the surface of the discharged sediment flowing away from the pipe. This could be done easily in the shallow runoff, which rarely exceeded 15 cm depth (6 inches). These crabs were examined in the same manner as basket sampled crabs.

Data Analysis

A stopwatch was used to record the time that sediment flowed through the basket (Sample Time). The proportion of total discharge that actually passed through the basket was estimated (% Discharge), to account for splashing or overshooting the basket. The product of these two variables equalled the actual minutes of dredge operation represented by a particular basket load, and was labeled Discharge-minutes, or Dm. Thus:

Discharge-minutes = (Sample Time) x (% Discharge)

For each day on which sampling was conducted, Dm for each basket were combined into a daily total, and expressed as decimal hours. This time was multiplied by the average rate of dredging (cubic yards/hour), as shown on the contractor's daily reports, to obtain the estimated volume of sediment sampled (in cy). Crab entrainment was then evaluated as crabs/Dm or crabs/cy. An overall weighted average was calculated for each location where sampling occurred (Westport and Aberdeen), and individual daily estimates were averaged to obtain an alternative estimate with confidence intervals.

Ring Net Trapping of Crabs

On nine occasions in the Westport Marina, and two occasions at the PGH Terminal, ring nets baited with fish carcasses were used to capture crabs. In the Westport Marina, these occasions were: 2 before dredging commenced, 3 near the

operating dredge, 2 during the week after completion of dredging, and 2 six weeks after completion. At T-4 in Aberdeen, ring net samples were taken 2 weeks after the completion of dredging. Earlier sampling attempts had been prevented by flood conditions, and conflicts with other sampling schedules.

RESULTS

In the Westport Marina, 78 crabs were recovered from 321 cy of sediment, for an average entrainment rate of 0.243 crab/cy (Table 5-1). At T-4 in Aberdeen, only one crab was

Table 5-1. Sample sizes and entrainment rates for pipeline dredge MALAMUTE

Date	Samples	Time Dm	= Hours	Rate (cy/hr)	Volume (cy)	# of crabs	Crabs/cy	Crabs/Dm
Westport								
9/22/79	6	8.32	0.139	124	17.2	0	0.0	0.00
9/29/79	9	28.08	0.468	130	60.8	30	0.493	1.07
10/6/79	4	12.40	0.357	227	81.0	7	0.086	0.33
10/10/79	12	23.22	0.387	291	112.6	25	0.222	1.08
10/31/79	3	5.77	0.096	260	25.0	10	0.400	1.73
11/10/79	3	6.12	0.102	241	24.6	6	0.244	0.98
					321.2	78	0.243	
Aberdeen								
12/11/79	8	98.5	1.64	124	203.0	1	0.005	0.01
12/12/79	6	57.5	0.96	397	381.0	0	0.0017	0.00
					584.0	1	0.0017	
Visual Observations in Westport								
10/10/79		15.0	0.25	291	72.8	10	0.137	
11/7/79		20.0	0.33	233	77.4	0	0.000	

recovered from 584 cy, for a rate of 0.0017 crab/cy. This was a difference of 143-fold. Daily entrainment rates varied from 0 to 0.493 crabs/cy.

Visual observations of crab discharge from the pipeline were made on two occasions. This could be done easily by 3 or 4 observers wading through the shallow runoff, but only in Westport where the discharged material was stable enough to walk on. On October 10, 10 crabs were observed during 15 minutes, for an average of 0.137 crab/cy (Table 21). On November 7, no crabs were seen during 20 minutes of observation. This latter observation corresponded with ring net samples made earlier that day, in which only one crab was collected from the area being dredged (the old groin - see Figure 5). Likewise, very few seagulls were observed, and none were catching crabs on November 7, in contrast to most days when gulls were numerous and catching crab parts to eat. Although these visual observations corresponded reasonably well with basket sampling data, the visual observations were not included in the overall entrainment estimates.

Drastic differences in sediment consistency existed between the two dredged locations. In Westport, sediment was 10-25% gravel (of 1-5 cm diameter), and 75-90% sand. This tended to clog the sampling basket and fill it rapidly, so that baskets could only be set for an average of 2.5 minutes (Table 5-1). In contrast, sediment at the PGH Terminal in Aberdeen (about 17 km upriver from Westport) was 50% sand and 50% mud

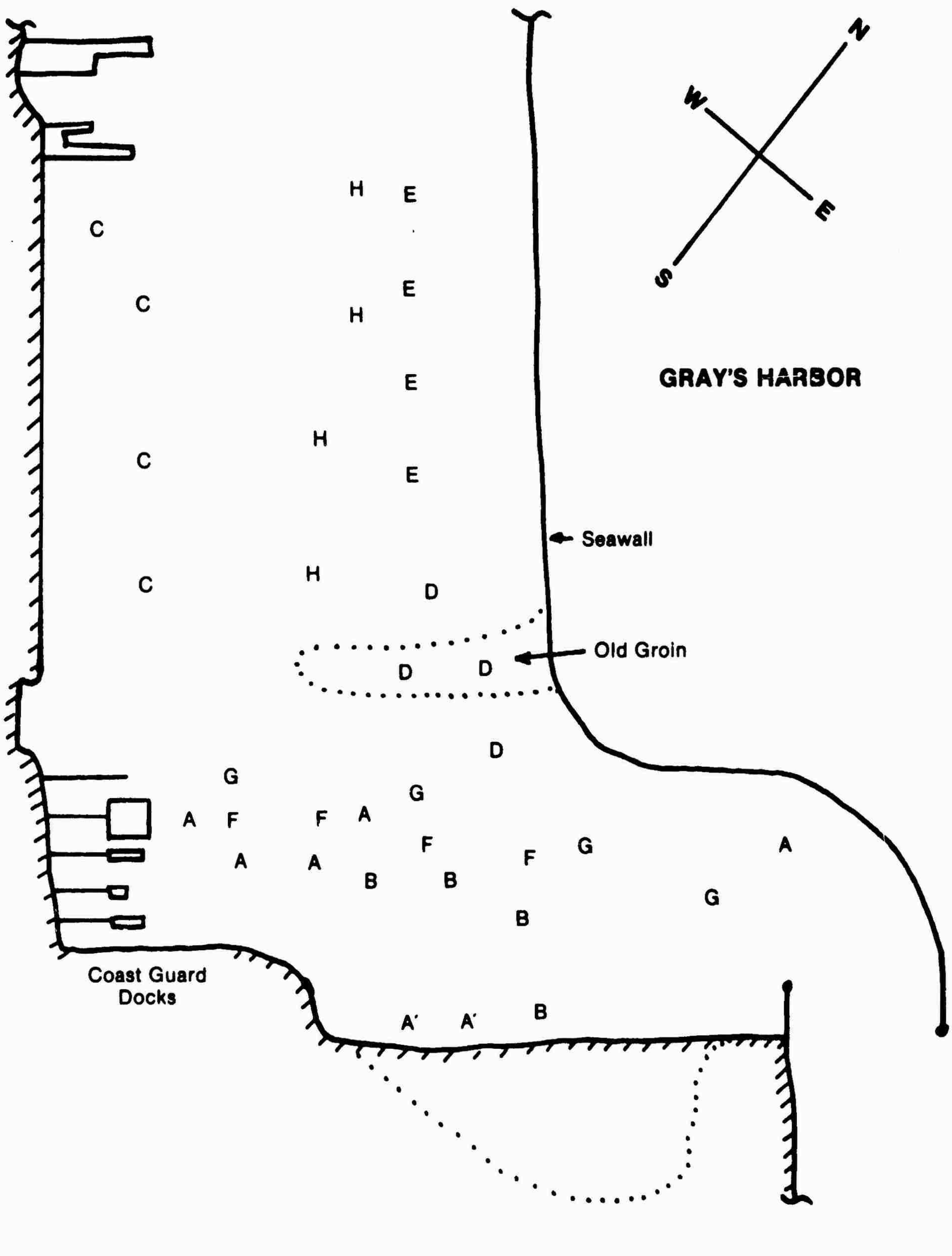


FIGURE 5. Southeast end of Westport Marina, showing location of ring net samples. Dotted line indicates shoreline prior to dredging. Dates and results of samples (capital letters) are given in Table 5-3.

and wood fiber. This material passed through the basket more easily and allowed sampling times averaging 10.2 minutes.

It is believed that no crabs escaped from the sediment disposal sites back into the environment from which they were removed, or if any did, their numbers were negligible. Therefore, all crabs entrained by the MALAMUTE were assumed to become mortalities. However, in order to document any mortality resulting from the sampling effort alone, comparisons were made between live and dead crabs from basket and surface collections. Of 49 crabs collected from the spoil surface by hand, 57% were dead and 43% alive (Table 5-2). Live crabs were easy to see in the runoff because of their struggling movements. Dead crabs were harder to locate, especially if in small pieces. For this reason, the proportion of dead crabs within this grouping may be higher than estimated. Of 70 basket-collected crabs, 86% were dead, and 14% alive. The difference in proportionate deaths was probably due to damage suffered by crabs upon impact with the steel basket in addition to the impact of sand and gravel on crabs in the basket. High pressure water from the discharge pipe also tended to mix the basket contents thoroughly, increasing the potential for damage to the crabs. Thus, the estimate of mortality for basket sampled crabs was positively biased. A better estimate of dredging-induced crab mortality is 72%, the average of the two estimates obtained. The sampling procedure, therefore, caused

Table 5-2. Crabs collected from all MALAMUTE samples.

Date	Basket-collected crabs #	Dead	Alive	Surface-collected crabs #	Dead	Alive
9/22/79	0	0	0	11	2	9
9/29/79	30	23	7	6	4	2
10/6/79	7	6	1	0	0	0
10/10/79	25	22	3	32	22	10
10/31/79	10	10	0	0	0	0
11/10/79	6	6	0	0	0	0
12/11/79	1	1	0	0	0	0
Total	79	68	11	49	28	21
Percent		86	14		57	43

an increase in crab mortality of about 20% over that caused by the dredging process alone.

Ring net trapping of crabs in the east end of the Westport Marina showed a high concentration of juvenile crabs (catch per unit of effort, CPUE = 48.0) prior to commencement of dredging operations (Table 5-3 (a) set A and A'; Figure 5). Crabs were also numerous around the active dredge in that area (Set B; CPUE = 17.5). Fewer crabs were collected during set C, near the active dredge, perhaps due to the use of clams for bait, instead of fish carcasses (see Discussion). Only one crab was caught during set D, while the dredge was removing the old groin. This structure had previously been above water, so was not inhabited by crabs. After the completion of dredging,

Table 5-3 (a). Results of crab trapping in Westport Marina.

Set	Date	Tide	# Nets	Total catch	Avg. width	CPUE	Comments
A	9/21/79	E. ebb	5	240	77.7	48.0	Before dredging
A	9/21/79	E. ebb	2	0	—	0	Before dredging
B	10/6/79	High	3	35	85.3	17.5	Near active dredge
C	10/31/79	L. ebb	4	29	90.7	7.3	Near active dredge Clams for bait
D	11/7/79	Low	4	1	145.0	0.25	Near active dredge on old groin
E	11/20/79	High	4	18	106.1	4.5	1 week after dredging
F[1]	11/20/79	High	4	32	97.1	8.0	1 week after dredging. Compare to A.
G[2]	12/29/79	High	4	94	93.0	23.5	6 weeks after dredging. Compare to A,F.
H	12/29/79	High	4	30	106.6	7.5	6 weeks after dredging Compare to E.

Table 5-3 (b). Results of crab trapping at Terminal 4, Aberdeen.

Set	Date	Tide	# Nets	Total catch	Avg. width	CPUE	Comments
I[3]	12/29/79	M. ebb	4	5	67.4	1.25	100' out from T-4
J	12/29/79	M. ebb	4	2	79.5	0.5	Opp. side of channel.

NOTES;

[1]Bottom water conditions: S=30.0 ppt, T=11.0° C
[2]Bottom water conditions: S=26.5 ppt, T=9.0° C
[3]Bottom water conditions: S=12.5 ppt, T=8.0° C

fewer crabs were caught in set E (CPUE = 4.5 crabs/net) than C (CPUE = 7.3 crabs/net) even though fish carcasses were used as bait. Set F produced a much lower catch than set A (CPUE of 8.0 vs. 48.0 crabs/net) although it was made at virtually the

identical site. Six weeks after dredging was completed in the marina, ring netting showed a slight increase from the catch of 11/29/70 (sets G and H). Set G produced more crabs than set F (CPUE of 23.5 vs. 4.5 crab/net). The crab population in the east end of the marina had returned to about half of its pre-dredging size (CPUE = 48.0 crab/net). Similarly, set H showed an increase from set E, to which it was almost identical. Tidal conditions were similar for sets F and G, and E and H (see footnotes, Table 5-3 (b)).

Only two ring net sets were made at the PGH Terminal in Aberdeen, on December 29, 1979, after completion of dredging there. Flood conditions had prevented earlier netting attempts. Catch per unit of effort (CPUE) was very low for both sets (1.25 and 0.5 crabs/net; Table 5-3 (b)). Although indicating the presence of crabs in the dredged area, CPUE data are difficult to compare between T-4 and the Westport Marina, due to different hydrographic conditions (see Discussion).

Average widths of crabs collected by ring net from the Marina prior to December 29, 1979 (83.1 mm), and of those collected by basket during dredge sampling (83.1 mm) were not significantly different (Tables 5-4 and 5-5). Therefore, entrainment by the dredge was not size selective. However, those crabs surviving initial entrainment had an average width significantly smaller ($p = 0.01$) than those that died, supporting the hypothesis that small crabs were less likely to be broken or smashed by the entrainment/sampling process.

Table 5-4. Size of crabs collected in Westport, from dredge MALAMUTE, and by ring net.

		Dredge		
Origin	Ring net[1]	All	Alive	Dead
Number (N)	356	100	33	67
Avg. width in mm	83.10	83.09	75.2	87.0
Std. dev.	20.5	21.4	16.4	22.6

[1]Does not include crabs trapped on 12/29/79

Table 5-5. Comparison of crabs recovered from MALAMUTE and Westport Marina, by two-sample "t"-test.

	Comparison	
Parameter	Nets vs. Dredge	Alive vs. Dead
Pooled variance (s^2_p)	427.28	431.68
Pooled std, dev. (s_p)	2.339	4.419
Difference in means	0.01	11.8
Test statistic (t)	0.0043	2.66
Degrees of Freedom	454	98
Critical Value	0.126	2.590
Alpha (Total)	0.90	0.01
Significance level	None	High

Although Dungeness crabs were abundant in Westport, few other organisms were encountered in the dredge samples. The most abundant secondary species were staghorn sculpin (*Leptocottus armatus*) and cockles (*Clinocardium nuttalii*) which numbered 37.4 and 28.0 per 1,000 cy, respectively (Table 5-6). At T-4 in Aberdeen, *C. magister* was less numerous than other species in the dredge soil, notably staghorn sculpins, Crangonid shrimp, and mud clams (*Macoma sp.*).

Table 5-6. Taxa collected by dredge MALAMUTE (other than *Cancer magister*).

	Westport		T-4	
	#	Density[1]	#	Density
Staghorn sculpin (*L. armatus*)	12	37.4	9	15.4
English sole (*Parophrys vetulus*)	1	3.1	0	
Stickleback (*Gasterosteus aculeatus*)	0		1	1.7
Gunnel (*Pholis sp.*)	1	3.1	0	
Sand shrimp (*Crangon sp.*)	0		5	8.5
Ghost shrimp (*Upogebia pugettensis*)	1	3.1	0	
Shore crab (*Hemigrapsus sp.*)	1	3.1	0	
Cockle (*Clinocardium nuttalli*)	9	28.0	0	
Mud clams (*Macoma spp.*)	2	6.2	0	
Unknown clam	0		4	6.8

[1]Density expressed as number of organisms per 1000 cy.

DISCUSSION

The total volume of sediment removed from the Westport Marina was 151,483 cy. If the estimated entrainment rate of 0.243 crab/cy is accurate, the total number of crabs killed during this dredging operation may have been 36,810, of which 36% (13,250) were females. Confidence intervals can only be calculated if the daily entrainment rates are treated as individual estimates. Their averate is 0.241 crabs/cy, with a standard deviation of 0.185. Thus the 95% confidence interval

is very wide, from 0.047 to 0.435 crabs/cy. This interval, applied to the total volume dredged in the Westport Marina, produces a 95% confidence interval about the total dredging related crab mortality of 7,120 to 65,893 crabs. This method of obtaining the confidence interval is dubious because daily samples were of greatly differing volumes, and smaller ones were subject to greater proportionate error in precise timing. Total volume of sediment dredged from the T-4 site was 114,962 cy. Based on an average entrainment rate of 0.0017 crabs/cy, the total dredge related mortality of crabs at the T-4 site was 194 crabs. Because only one non-zero value for entrainment was recorded, no confidence interval could be calculated.

Prior experimentation with sampling techniques, and experience with the method used, has shown this method to be the most precise and consistent method known to us for sampling crabs from dredges. However, due to the technical difficulty of handling heavy equipment in a precise manner, several problems arose in data interpretation. Samples taken in Westport tended to be of very short duration. The primary reason for this was sediment composition, as previously described. Therefore, numerous samples (6-12) had to be taken on any day. On three of the six sampling days in Westport, total sampling time (in terms of discharge-minutes) was less than 10 minutes, as a result of several recurring conditions. Occasionally, the dredge would shut down entirely for hours or days for repairs or rearrangement of the pipeline. More often

than that, sampling was interrupted by working requirements of the dredge crew, such as extension of the pipeline, lunch hours and shift changes. Perhaps the most frustrating condition was the inability of the discharged material to support the heavy machinery used to handle the baskets; after 2 or 3 samples, the bank would collapse. Sometimes the dredge crew would rebuild it, but often it was not feasible to keep doing so.

As a result of these conditions, samples of 5-10 or 20-30 minutes must represent an entire week of dredging. Admittedly, these were small samples; total volume sampled represented 0.21% of all material dredged from the marina. Sampling error was reduced by spreading the sampling effort throughout the entire 6 weeks of dredging and taking samples from 5 or 6 areas within the marina. In contrast, dredge samples taken at T-4 were concentrated over a short period of time (2.5 hr in two days) so only depict the entrainment rate over 50-100 m (165 - 330 ft) of linear dredge movement along the 710 mm (2330 ft) path dredged at T-4. Since sampling at T-4 was not spread throughout the entire dredging effort, these samples were subject to greater sampling error and crab population variability than those taken in Westport. However, the volume of sediment sampled was greater at T-4 than in Westport, representing 0.48% of total volume dredged during this operation.

Another sampling problem rests in the assumption of method efficiency: Did the basket retain all crabs that entered it?

All crabs and crab parts found in the basket were of fairly uniform size, at least 2 or 3 times as large as the mesh opening. Therefore, it is unlikely that crabs were broken into pieces small enough to completely pass through the wire mesh (except for legs). Much splashing did occur, but attempts were made to account for it in the estimations of % Discharge. Another question remains: Would splashing, which accounted for 5-25% of total discharge, also take with it an equivalent amount (5-25%) of total entrained crabs? None of the collected data can be used to answer that question, so the assumption must be made that losses due to splashing were proportional. However, no crabs or crab parts were ever seen to splash out of the basket, though such observations would have been difficult to verify. I feel that most crabs and large pieces thereof probably would have stayed in the basket, due to their size and weight.

Variability in crab populations presents other problems in interpretation. Ring netting in the Westport Marina seemed to indicate a high predredging crab population, which declined during dredging to low numbers. Six weeks afterwards, a slow increase in this crab population was detected. This pattern was most prevalent in the east end of the marina. Conditions that may have contributed to this apparent decline and re-population are:

1. Crabs were entrained by the dredge.

2. Crabs were scared away by the action of the cutter head, or changes in water quality.

3. Crabs vacated the area after dredging removed all former food sources.

4. Increased current in the marina, caused by groin removal, made the area less desirable as habitat.

5. These figures may represent natural variability in crab population densities.

It may be that all of these conditions contributed to the CPUE data in the order suggested.

Differences in crab trapping data between Westport and the PGH Terminal (T-4) site were probably due to differing environmental conditions as well as different crab population densities. The Westport Marina was relatively calm and shallow, rarely exceeding 9 m (30 ft) at high tide, with currents less than 0.5 knot (marina currents have increased to about 1.7 kt at maximum ebb since removal of the groin, according to USACE). Also, water quality is more oceanic, with bottom salinities of 26-30 ppt at high tide. In contrast, T-4 lies adjacent to one of the deepest parts of the ship channel (15 m at high tide), and is subject to high currents of 2.0 kt or more (source: NOAA tide and current tables). Water quality there fluctuates from fresh to brackish, and bottom salinities of from 0 to 26 ppt have been measured on different tides. Successful ring net sampling depends on several factors:

1. type of bait used,

2. willingness or ability of crabs to enter the trap,

3. lack of current or surface disturbances,

4. depth of water,

5. skill of the operator; ability to keep crabs in trap while lifting.

Factors 1 and 2 are less important, although experience has shown that fish carcasses make better bait for this gear type, so were used for all but one netting sequence. Current can make it difficult for crabs to detect bait, while both current and depth can increase the difficulty in determining when the net has lifted off the bottom. Consequently, conditions for ring netting were near optimum in the marina, but much less so at T-4. The crab population may have been greater at T-4 than detected, but was still much lower than in the Westport Marina.

If these limitations are temporarily overlooked, crab population sizes differed between Westport and T-4 by a factor of 16 (avg. CPUE 14.1 vs 0.88). Though this factor may vary widely (from 10 to 100?) the difference in entrainment rate was 143-fold. Ring net sampling on December 29, 1979 was done on tides identical to those which occurred during dredge sampling at T-4 (Table 5-7). I conclude that entrainment was disproportionately lower at T-4 than in Westport, i.e., fewer crabs were caught at T-4 due to greater escapement, in addition to the smaller population size. Data collected aboard the hopper dredge PACIFIC, while dredging the upper reaches of the ship channel, indicated a similar conclusion. PACIFIC crew members indicated that the drag head often sank down in the soft sediments present in the upriver reaches (including the

Table 5-7. Tide levels during MALAMUTE sampling.

Date	Time of sampling	Tide[1]	Nearest slack	Slack level[2]	Crabs (#/cy)
9/22/79	1200 - 1330	F	1349	9.6	0.0
9/29/79	0930 - 1525	E-LS	1258	4.0	0.493
10/6/79	1020 - 1130	F	1320	11.4	0.086
10/10/79	0930 - 1400	LS-F	1024	2.4	0.222
10/31/79	1030 - 1130	HS	0946	10.2	0.400
11/10/79	1100 - 1200	LS	1143	4.3	0.244
12/11/79	0900 - 1200	E	1303	4.3	0.010
12/12/79	0900 - 1230	E	0826	10.1	0.000

[1]Tidal abbreviations: F = Flood, E = Ebb, LS = Low slack, HS = High slack

[2]Feet above MLLW

T-4 area) and acted like a plow, perhaps frightening off crabs more effectively. The draghe[illegible] of the MALAMUTE may have behaved similarly. Or, the rotating cutter head may have stirred up more debris when operating in soft sediment than when operating in sand, allowing greater escapement due to this disturbance. Then again, differences in entrainment rate between Westport and T-4 may have been real and accurate reflections of transient crab population densities.

SUMMARY

1. Pipeline dredge sampling in the Westport Marina for 6 days produced 78 Dungeness crabs from 321 cubic yards (cy) of sediment for an average entrainment rate of 0.243 crabs/cy.

2. Pipeline dredge sampling at Terminal 4 in Aberdeen for 2 days produced only 1 crab from 584 cy, or an entrainment rate of 0.0017 crabs/cy.

3. All crabs entrained by the pipeline dredge become mortalities when discharged into upland disposal sites. Dredge induced mortality was estimated at 72%, when excluding the disposal method.

4. The total crab mortality as a result of dredging in the Westport Marina was estimated to have been 36,810 crabs including 13,250 females (95% confidence interval: 7,120 to 65,895). At T-4 in Aberdeen, total crab mortality was estimated to be 194 crabs.

5. Crab population densities between the two sampling locations differed by a factor of 16, probably as a result of different environmental qualities.

6. The difference in entrainment rate between the two sites sampled was 143-fold.

7. Entrainment at T-4 was disproportionately low, perhaps due to interaction between sediment type and dredge operational characteristics.

8. The crab population in Westport Marina appeared to exhibit a decline during dredging to low levels, followed by a slow increase during six weeks of post-dredging sampling.

SECTION 6

COMPARISON OF CRAB ENTRAINMENT AND MORTALITY ABOARD FOUR DREDGES SAMPLED

ENTRAINMENT RATES

Entrainment rates for the dredges sampled are shown in Table 6-1. The lowest entrainment (0.0017 crabs/cy) was exhibited by the pipeline dredge MALAMUTE while operating at the Grays Harbor Port Terminal in Aberdeen (T-4), whereas the highest entrainment rate (0.243 crabs/cy) was exhibited by this same dredge while operating in the Westport Marina. These two locations showed the lowest and (probably) highest crab population densities, respectively, of all areas sampled during this study. Despite the use of ring nets in those two locations, the enormous number of juvenile crabs recovered in the marina was considered to represent a similar or greater population density than the numbers of adult crabs recovered by pots in the South Reach Channel.

The high entrainment value recorded on the MALAMUTE was not greatly different from those shown by the SANDSUCKER or PACIFIC. Before comparison of these values by analysis of variance (ANOVA), daily entrainment rates for the SANDSUCKER were converted from a basis of crabs-per-minute to units of crabs-per-volume (Table 6-2). No significant difference was found between the mean entrainment rates observed aboard these

Table 6-1. Comparison of crab entrainment rates of four dredges sampled.

Dredge	VIKING	SANDSUCKER	PACIFIC	MALAMUTE	
Type	Clamshell	Suction (hopper-barge)	Suction (hopper)	Suction with cutter and pipeline	
Area sampled	S. reach (E. end)	S. reach	S. reach & Cross-over	Westport Marina	T-4
Sediment vol. sampled (cubic yds)	86.5	463	1,058	321	584
No. crabs recovered	1	107	163	78	1
Entrainment rates: (crabs/cy ± 1.0 s.d.)					
Averaged daily rates	*	0.223±0.110	0.226±0.212	0.241±0.185	*
Weighted overall	0.012	0.231	0.182[1]	0.243	0.0017
Entrainment factor[2]	20.05	1.00	0.79	1.05	0.007

[1]Only South Reach Stations are included in this estimate, due to differential action of drag head at 3 other stations (see Section 4)

[2]Entrainment factor = weighted entrainment rate (w.e.r.) divided by w.e.r. of SANDSUCKER.

*Values could not be calculated from the data collected.

three suction dredges (Table 6-3). Reasons for this lack of significance fall into two categories: a) data variability, and b) data incompatibility. Variability among the individual observations was greater than the variability between the means for each dredge (indeed, it is the primary purpose of the ANOVA

Table 6-2. Conversion of SANDSUCKER entrainment rates to volume basis.

Sample time (in Discharge minutes) Method 1	Method 2	Avg.	Volume sampled (time) x (8.7) = cu. yds.	# of crabs collected	crabs per cubic yd
4.2	4.5	4.35	37.9	5	0.132
10.2	9.6	9.90	86.1	30	0.348
4.6	4.4	4.50	39.2	7	0.179
13.2	12.2	12.70	110.5	9	0.081
11.2	10.6	10.90	94.8	33	0.348
11.2	10.6	10.90	94.8	23	0.243
				Mean	0.222
				std. dev.	(0.111)

Table 6-3. ANOVA of individual estimates of suction dredge crab entrainment rates. Values given are number of crabs per cubic yard.

	Dredge SANDSUCKER	MALAMUTE	PACIFIC
	0.132	0.0	0.126
	0.348	0.493	0.212
	0.179	0.086	0.615
	0.081	0.222	0.039
	0.348	0.400	0.071
	0.243	0.244	0.295
Total	1.331	1.445	1.358
Mean	0.222	0.241	0.226

ANOVA Table

Source	Degrees of freedom	Sum of squares	Mean square	F-value	Probability level
Total	18	1.409			
Mean	1	0.949			
Treatments	2	0.002	0.001	0.032	0.75
Residual	15	0.458	0.031		

to elucidate such facts). These findings indicate that natural variability in the distribution of crabs on the harbor bottom is so great as to overshadow any variability detectable between the dredges sampled. However, not all data used were of the same type; SANDSUCKER and MALAMUTE data represent the results of six different sampling days, over a large area (1-2 km) versus a small area (0.5 km), whereas the PACIFIC data represent results from six non-adjacent locations. Furthermore, equal sample sizes could never be obtained, due to the idiosyncrasies of dredging operations, and therefore ranged from 17.3 to 548 cy. In an ANOVA, all data points are assumed to represent equivalent sample sizes or techniques, and are therefore assigned equal weight.

Of those dredges sampled in the South Reach Channel (VIKING, SAUDSUCKER, PACIFIC) the VIKING exhibited the lowest entrainment rate. This quality was considered to be a direct consequence of its clamshell-type operation, as opposed to the suction mode of the other dredges.

Entrainment rates for each dredge were compared to that of the SANDSUCKER, and an Entrainment Factor (E.F.) was computed for each (Table 6-1). The SANDSUCKER was chosen as the basis for this comparison because it produced the most consistent data, as a result of the fewest sampling problems (and subsequent sampling error), the narrowest range of entrainment values, and the smallest confidence interval for the mean. Additionally, that dredge has been most commonly used for

channel maintenance and modification in Grays Harbor during the past two years.

In summary, the three suction dredges all exhibited high crab entrainment rates, whereas the clamshell dredge VIKING exhibited a rate approximately twenty times less than these (E.F. = 0.05). Among the suction dredges, the pipeline dredge MALAMUTE exhibited both the highest and lowest entrainment rates (E.F. = 1.05 and 0.007) depending upon location. The SANDSUCKER showed a slightly, but not significantly lower value (defined as unity), and the PACIFIC even lower yet (E.F. = 0.79). These differences could be solely the result of different densities of crab populations in the areas sampled. Conversely, real differences in entrainment rates could occur as a result of differences in pump diameter or speed, or other operational characteristics.

Entrainment rates depended primarily upon dredge type (suction vs. clamshell). Among the suction dredges, entrainment appeared to be a function of location sampled - probably correlated with crab population densities and sediment quality. This latter facet was manifest in the extremely low or zero values of crab entrainment exhibited by both the PACIFIC and the MALAMUTE when dredging soft sediments.

MORTALITY

Mortality estimates varied widely among the four dredges (Table 6-4). Due to the low entrainment rate observed aboard

the VIKING, mortality could not be estimated, so was assumed to be equally low (<10%). Immediate mortality aboard the hopper dredges could only be estimated indirectly. For the SANDSUCKER and MALAMUTE, higher mortality was observed among crabs collected in samples than among crabs recovered from the surface of the discharged sediment. Both of these values were concluded to be biased in opposite directions; the sampling procedures increased the immediate mortality somewhat, whereas the recovery of crabs from the spoil surface tended to produce a high proportion of healthy crabs, while overlooking crabs that had been injured or killed and subsequently buried. Therefore, the only estimate of mortality obtainable from these two sources was an average, being 45% for the SANDSUCKER, and 72% for the MALAMUTE. However, as explained below, ultimate mortality was probably 100% for the MALAMUTE.

Table 6-4. Crab mortality observed aboard sampled dredges.

	% Deaths Among Recovered Crabs				
Dredge	Sampled	Other crabs	Estimated for dredges	Delayed	Total
VIKING	0%	*	(Unknown but very low)		
SANDSUCKER	61%	30%	45%	19%	56%
PACIFIC	67%	*	67%	19%	73%
MALAMUTE	86%	57%	72%	100%	100%

* Data not possible to collect.

No crabs could be recovered from the hopper of the PACIFIC for mortality comparisons. However, it was concluded that the sampling conditions approximated the normal entrainment conditions, whereby entrained crabs were discharged at great velocity against a solid metal splash plate, to warrant considering the observed sampling mortality as approximately equal to the true immediate mortality.

Delayed mortalilty was estimated numerous times. Estimates obtained during the SANDSUCKER sampling periods were later disregarded, as they were obtained under sub-optimal conditions. Estimates obtained during the PACIFIC sampling periods were much better due to the construction of a large flow-through seawater aquarium. Death of crabs due to exposure (removal from water) was estimated four times, of different duration, and their weighted average was used. Delayed mortality of crabs recovered from the PACIFIC (34%) minus the estimated value for exposure-induced mortality (15%) resulted in an estimate of delayed mortality as a result of dredge-induced injury or stress (19%). This proportion, applied to the estimates of immediate mortality for the SANDSUCKER and PACIFIC resulted in expected total mortalities of 56% and 73%, respectively (Table 6-4). Delayed mortality, and subsequently, total mortality, was presumed to be 100% for crabs entrained by the pipeline dredge MALAMUTE. As previously discussed (Section 5), discharge of crabs into diked landfill sites probably allowed negligible escapement.

Estimates of total mortality were therefore lowest for the clamshell dredge, highest for the pipeline dredge, and intermediate for the two hopper dredges (Table 6-4). Of the two hopper dredges, SANDSUCKER and PACIFIC, the latter caused the greater mortality, presumably due to the splash plate. If potential mortality is designated as the product of total mortality and entrainment rate, the two hopper dredges were approximately equal in destructive capability, as shown in these equations:

Potential mortality (P.M.) (crabs/cy) = (entrainment rate) x (total mortality)

For SANDSUCKER:

P.M. = (0.231) x (0.56) = 0.129 crabs/cy

For PACIFIC:

P.M. = (0.182) x (0.73) = 0.133 crabs/cy

In other words, although the PACIFIC entrained fewer crabs per volume, its total mortality was greater, making it equally as deadly as the SANDSUCKER. For each 1,000 cubic yards of dredged sediment, the PACIFIC may entrain 182 crabs, of which 133 might die, whereas the SANDSUCKER may entrain 231 crabs, of which 129 might die. Of course, this discussion is based upon the assumption that the weighted entrainment rates were valid. If the use of averaged daily entrainment rates (which were not significantly different between the dredges) was more valid than the use of weighted overall rates, then the total mortality (Table 6-4) would be a better indicator than the potential

mortality. Potential mortality should also include an estimate of crab abundance as a weighting factor. However, the PACIFIC and SANDSUCKER were both sampled in the South Reach within a mile of each other. While crab populations may vary over that distance, only one crab pot station was nearby ("E", see Section 7). The next closest station, "D", produced very similar catch effort data (Figure 8, Section 7). Sampling stations were not spaced close enough together to provide data for crab abundance weighting factors in this region.

EFFECTS OF BURIAL

Total mortality of crabs aboard the hopper dredges could be increased by burial of crabs under up to 4-5 m of sand (13-16 ft). The magnitude of such additional mortality was not assessed during this study. Chang and Levings (1978) showed that *Cancer magister* was incapable of escaping burial under 0.2 m of sand or more, but could remain there up to 72 hrs with no ill effect. Conditions on the hopper dredges were different from those imposed by these authors. Crabs which survived the initial entrainment, passage through the pump, and discharge into the hopper, eventually sank to the sediment surface, and may have buried themselves in it as a protective measure. Consequently, they would have been instantly buried by additional spoil deposited on top of them. Crabs remained in the hoppers probably no longer than 4 hours. While buried in sand, some respiratory exchange could conceivably have occurred between a

crab and the water immediately surrounding it. Whether or not these conditions would lead to suffocation of the crab due to local CO_2 buildup and/or O_2 depletion is unknown. Such mortality due to suffocation might have been of a magnitude equivalent to the exposure-induced mortality estimated during the survival experiments since both arise from lack of oxygenated waters. If so, the estimated delayed crab mortality from hopper dredging would remain at 34%, as opposed to 19%, and the total mortality would be increased from 56 to 64% for the SANDSUCKER, and from 73 to 78% for the PACIFIC.

Injured crabs would probably be more susceptible to the effects of burial than uninjured crabs. However, the effects of delayed mortality were estimated using both injured and uninjured crabs, so should be an adequate index.

CAUSES OF DEATH

The most common cause of death was total smashing of the crab, or other major body damage, such as loss of all legs, or separation of thorax and carapace. Delayed death was the result of smaller or fewer injuries, such as loss of abdomens, loss of 3 or more legs, or small cracks and punctures in the exoskeleton. The cause of death to this group of crabs could have been loss of blood, compounded by the presence of sand in the hemocoel and gill arteries, which may have blocked circulation. The seriousness of small cracks and punctures in the exoskeleton depended upon the degree to which the epidermis had

been damaged. Many crabs showed signs of healing when small pieces of carapace were lost without damage to the underlying epidermis.

Damage to entrained crabs could have occurred at four points during passage from environment to hopper:

1) Damage inflicted by the cutter/drag head as crabs were encountered.

2) Damage occurring during passage through the pump; mulching by pump blades.

3) Damage due to bombardment by sand, gravel, or debris, while still inside the dredge machinery.

4) Damage due to discharge against a solid object, such as a splash plate, or structural components of the hopper.

The pump was probably the major source of damage, followed by the splash plate (PACIFIC) and the drag head itself. Mixing with sediment may have increased the damage to already injured crabs, but probably caused little additional damage. Another, unmeasured, source of mortalilty was scavenging by seagulls, which removed crabs from the surface of the spoil. This source would probably have contributed less than 1% to the total mortality, however, as no more than two or three crabs were ever observed to be taken from a single barge-load.

ADDITIONAL CONSIDERATIONS

During sampling aboard the VIKING, the possibility of higher initial entrainment was considered. For this reason, numerous clamshell dredge samples were taken from virgin ground

outside the channel margins in order to simulate the effects of initial impact. Although the effect of this upon crab mortality could not be evaluated because of the low crab catch, there was a marked difference in the catch rates of less mobile species (ghost shrimp, polychaetes, and clams) between the virgin samples and samples from previously dredged areas. The effect of initial impact may be considerable for some species, but is reduced for crabs due to their greater mobility.

An important distinction between the operation of clamshell and suction dredges, such as the VIKING and SANDSUCKER, respectively, was that the VIKING operated from a stationary position, while the SANDSUCKER was constantly moving. Once the VIKING started digging in a given area, most of the crabs may have been alerted to its constant presence, and departed from the area being dredged. In contrast, after the SANDSUCKER dredged a particular site, an interval of at least one hour or more would pass before it returned to the same location. Often, an individual site was not dredged more than once per hopper load. While dumping, the dredge would travel several kilometers from the dredge site. During those periods crabs may have moved slowly back into the previously dredged path from surrounding areas, and replenished the depleted population. Being scavengers, crabs may have been "lured" into a dredged track looking for food organisms loosened or killed by the passing drag head. Thus, crab mortality as a result of dredging by hopper dredges may not be confined to the initial

sweep of the dredge. This mortality may occur each time the dredge makes repeated sweeps in a given area, as more crabs are drawn in to replace those removed by the dredge. Such an effect might also account for our inability to distinguish a higher initial impact.

There was clearly a discrepancy between sex ratios of crabs collected on the SANDSUCKER at various times (1.08-1.41:1.0; M:F) and those collected during crab pot or ring net sampling nearby. Male/female ratio of the VIKING ring net samples was 4.1:1.0. Sex ratio of all crabs caught in pots near the VIKING was 23:1 (Oct. 21, 23, 28, and 30). The difference between trap-sampled and dredged-sampled sex ratios probably resulted from the fact that pots and ring nets are size-selective gear. Pots captured only the larger crabs, and thus fewer females, which are smaller, and present in fewer numbers among the larger size classes. Ring nets captured smaller crabs than pots, but are still somewhat behavior-dependent, i.e., they probably do not catch a statistically random sample of both sexes of crabs. The dredge suction head was not size-selective. This hypothesis was substantiated by comparison of the mean size of crabs recovered from the MALA-MUTE, and those trapped in the Westport Marina (Section 5).

SUMMARY

1. Crab entrainment rate was primarily a function of dredge type (suction vs. clamshell). The differences were partially associated with moving (hopper dredges) vs. stationary (clamshell dredge) operating conditions.

2. Three suction dredges were shown to have entrainment rates that did not differ significantly, when operated in sandy bottom areas (SANDSUCKER = 0.231 crabs/cy, PACIFIC = 0.182 crabs/cy, MALAMUTE = 0.243 crabs/cy). The clamshell dredge VIKING entrained crabs at a much lower rate (0.012 crabs/cy).

3. Among the suction dredges, entrainment varied widely between sampling dates and within samples, probably correlated with natural temporal and spatial variability in crab population densities.

4. Much lower entrainment rates were recorded for two suction dredges (PACIFIC and MALAMUTE) operating in silty mud, than would have been expected by comparison of crab densities between those areas and areas with sandy bottoms. This indicated the possibility of an abnormal action by the suction head in soft sediments.

5. Total dredging-related crab mortality rate was shown to depend on entrainment rate and method of sediment discharge. Open bin discharge was less damaging (as on the SANDSUCKER, with 56% mortality) than discharge against a splash plate (PACIFIC, 73% mortality). Most damaging was discharge into diked upland disposal sites (MALAMUTE, 100% mortality).

SECTION 7

CRAB DISTRIBUTION SURVEY

The presence of Dungeness crabs in Grays Harbor has been known since the early 1900's when the first commercial fishery started. Commercial catches inside the harbor have ranged from 25,000 to 220,000 lbs between 1970 and 1973 (Tegelberg and Arthur, 1977). Large numbers of adults have been observed incidental to surveys of oyster beds near Whitcomb Flats, and juveniles have been caught in beach seines near Hoquiam.

During the previous dredging effects study of 1974-76 (Tegelberg and Arthur, 1977), exploratory sampling for crabs was conducted at 10 stations throughout the harbor, utilizing crab pots, ring nets, and a beam trawl. Catches were not comparable between gear types due to size selectivity. Trawl catches included the smallest crabs, but also fluctuated more so than other gear types. Crabs were consistently caught as far upstream as Cow Point, near Terminal 1 at Aberdeen, and in salinities as low as 9-10 ppt. Crabs in the eastern (upstream) half of the harbor were smaller than crabs in the western portions. A high ratio of males to females was observed for crabs larger than about 75 mm carapace width. Few females over 120 mm, or males over 140 mm were encountered, indicating that crabs probably migrate into the ocean as they mature. Large numbers of crabs utilized the flats and sinks, especially along Whitcomb Flats, and in the area between the North and South

channels (west of Rennie Island). No seasonal shift in abundance of crabs was demonstrated except for low catches in January at Cow Point.

For the present study, more information was required concerning seasonal or monthly variations in crab abundance, and documentation of crab presence in those areas dredged. Therefore, a systematic study was undertaken utilizing crab pots at 5 stations along the ship channel.

METHODS AND MATERIALS

Twice monthly from January 20, 1979 to March 18, 1980, 3 crab pots baited with razor clams were set at each of 5 stations in the harbor, labeled A through E (Table 7-1). All pots were set on a single day, left to soak for 24 hours, and recovered the following day (24 hour set). Pots were set at the edge of the channel so that they would not pose any navigational hazard. Setting and recovery was usually accomplished aboard the WISHKAH, a 6.7 m (22 ft) crab boat with a 135 hp inboard/outboard gas engine, hydraulic winch, and overhead block. Small commercial crab boats were chartered occasionally, when weather or mechanical problems prohibited operation of the WISHKAH.

Sampling was performed during a neap tide cycle and a spring tide cycle in each month. Neap tide or spring tide are defined as the 24-hour period (from setting to recovery) during which the tidal exchange (sum of differences in slack tide

elevations) is the least or greatest, respectively, for the month. Neap and spring tide cycles usually occurred 6-10 days apart.

Table 7-1. Crab distribution sampling stations.

Station	Location	Depth[1] (m)	Distance[2] (km)
A	Cow Point. S. side of channel opposite buoy "51".	4.5 - 6.0	21.75
B	North Channel near Hoquiam. S. side of buoy "44".	6.0	18.28
C	Junction of Moon Island Reach and Crossover Channel, between buoys "30" and "32".	6.0 - 7.5	12.98
D	Junction of Crossover Channel and South Reach, NW of buoy "25".	6.0	8.68
E	West end of South Reach. N of buoy "15A".	8.0 - 9.0	5.03

[1]Depth at mean lower low water.
[2]Distance in km from Grays Harbor mouth at 46°55' N. latitude, 124°10' W longitude.

The crab pots used were 18.2 kg (40 lb) bay-type crab pots with 84 cm (33 inch) bottom diameter and 79 cm (31 inch) top diameter. Each of the two entrance tunnels in each pot had two double-finger triggers. The pots were woven with a 5 cm (2 inch) mesh, and had no escape rings.

Pots were emptied upon recovery, and crabs were sexed and measured. Width was measured to the nearest millimeter across the back of the carapace, between the notches just anterior to the 10th anterolateral spines. Bottom water temperature and

salinity were usually measured at each station. During January - July of 1979, a YSI electric conductivity meter was used for this purpose, until it failed due to salt water exposure. No measurements were then made until November, when a hand held refractometer/salinometer (AO Instruments) and a Van Dorn type water sampling bottle were purchased. These instruments were used thereafter.

RESULTS

Crabs were recovered from every station on every sampling occasion except at station A on January 20, 1979. Original data was recorded separately for male and female crabs. However, sexes were combined for data analysis, as only number and size of crabs was considered to have any bearing on dredge effects. Male/female ratio could not be accurately determined by pot catches, as these ratios may differ according to gear used.

Crab Size Distribution

From the earliest samples it was apparent that the average size of crabs captured by pots increased from station A to station E, as distance from the harbor mouth decreased (Figure 6). The smallest crabs were caught at the upstream stations (A,B). A single factor analysis of variance (ANOVA) was performed on average crab widths from each sampling date. Means for each location were compared. Analysis revealed an extremely

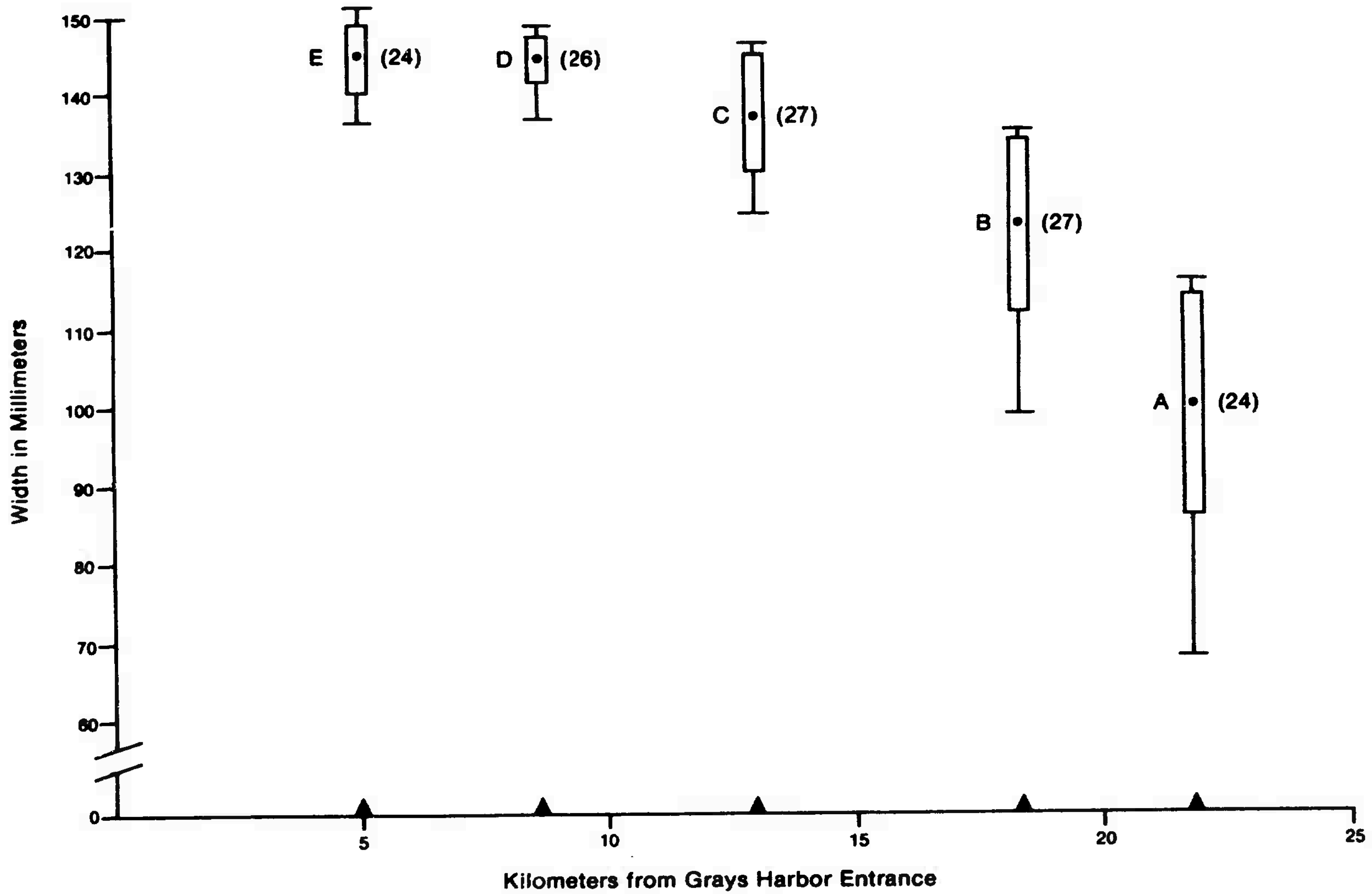


FIGURE 6. Crab carapace width versus station location. Dot represents mean; inner bar is ±1.0 standard deviation; outer bar is range. Only sample means included, number in parentheses.

significant location effect (Table 7-2), thus supporting the findings of Tegelberg and Arthur (1977), i.e., large crabs generally occur near the mouth of Grays Harbor, whereas small crabs can be found farther upstream.

Table 7-2. One-way ANOVA of crab widths, by station.

Source	Degrees of freedom	Sum of squares	Mean square	F-value	p
Treatments*	4	30,550	7637.5	29.80	0.001
Residual	105	26,913	256.3		
Total	110	1,884,167			

*Treatments = 5 stations, n = 22 samples. Samples excluded due to incomplete data were Jan. 20, April 26, Nov. 4, and Dec. 3, 1979.

Size increases due to growth were not readily apparent from pot data, but some growth could be detected at station A (Appendix C-1). At that location, average size was low in January 1979, but gradually increased through June, possibly due to a predominance of two-year-old crabs which grew through that period (Figure 7). After June, many crabs over 120 mm were caught, but few less than 90 mm. These were probably three-year-olds which maintained a stable average size until December, when those over 120 mm declined in the catch and were replaced by crabs in the 60-90 mm size range, probably two-year-olds. Thus the average size declined from November, 1979, through January of 1980.

Stations D and E produced the largest crabs, the narrowest range of sizes, and the most stable average sizes, remaining

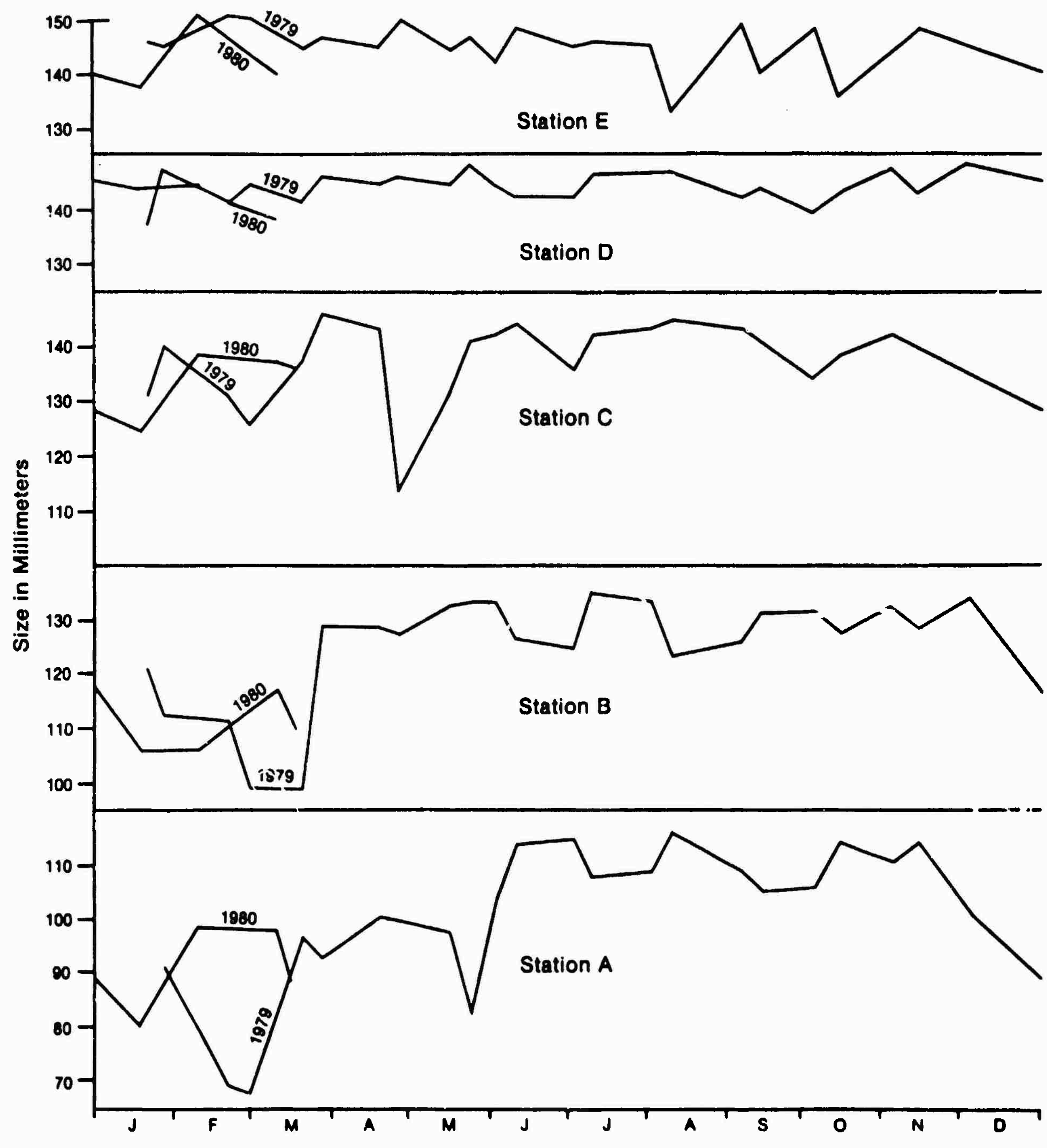


FIGURE 7. Average widths of crabs in pots, by station, 1979-1980.

between 145 and 150 mm (Figures 6 and 7). Station E produced a slightly wider range of sizes than station D.

At all stations except D, the average size of crabs decreased from December, 1979, through January, 1980, to sizes smaller than those observed in January of 1979.

Catch Per Effort Analysis

Several biases were involved in computing catch per unit of effort from crab pot data. Generally, crab pots were size selective. The pots used in this study, having about a 50 mm mesh size, retained few crabs less than about 65 mm wide. Additionally, pots may be behavior dependent. The presence of large crabs in a pot may deter the entrance of smaller crabs and/or females. Therefore, when reviewing catch per effort data one should bear in mind that the catchable portion of the population included only those crabs within a certain size range, and may have excluded most females.

Three weak trends were revealed by CPUE data. The first of these concerned only stations A and B, where crabs were least abundant, and of smallest size, during the winter months (especially February) and more abundant during summer and fall (Figure 8). Catch per effort increased slowly throughout the year at station A, but no such trend was apparent at station B.

A second pattern, seen at stations C-E, was just the opposite of that seen at stations A and B. Crabs were generally

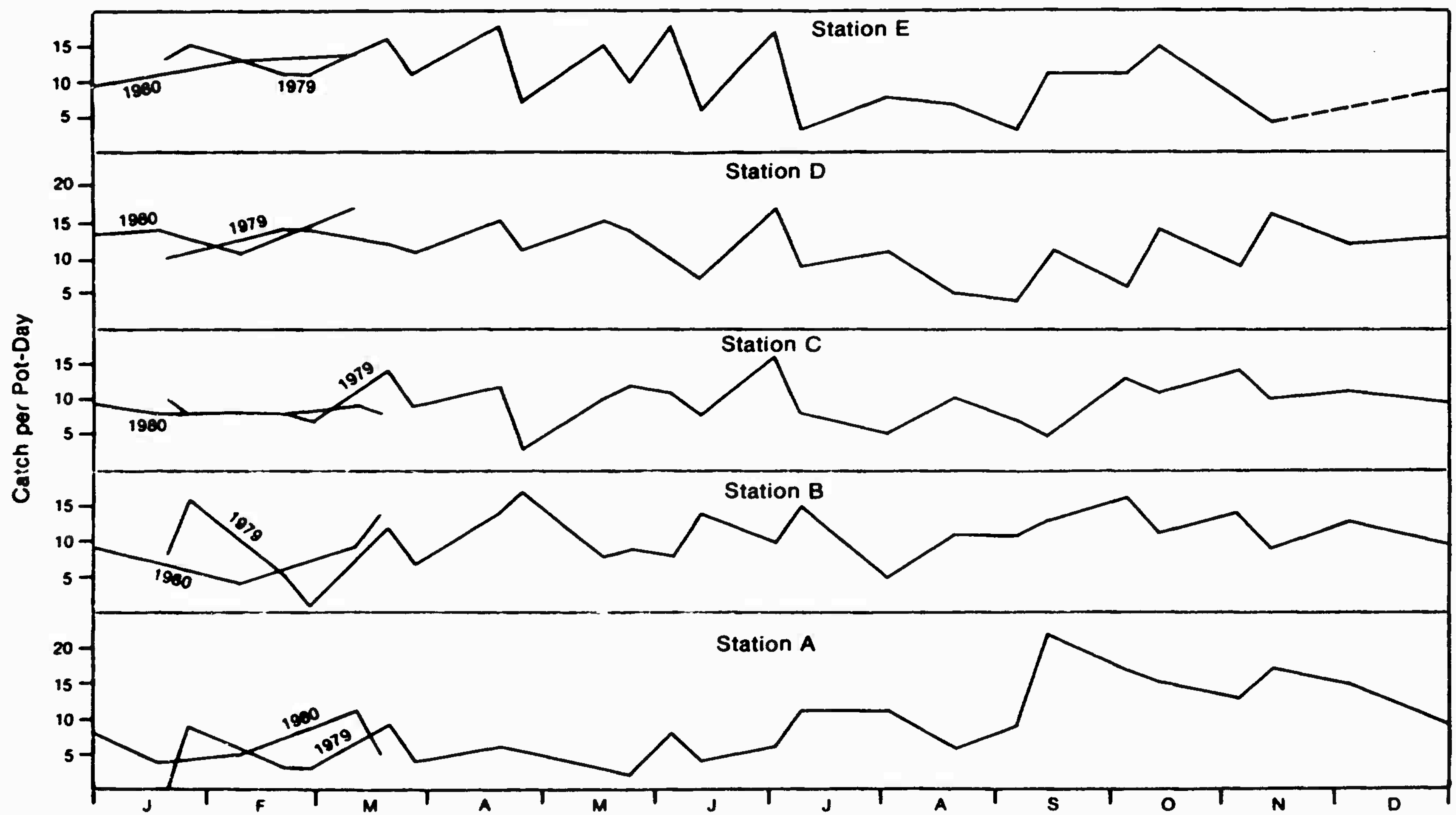


FIGURE 8. Catch per effort of crabs in pots, by station, 1979 - 1980. Broken line indicates incomplete data.

available to the gear throughout late winter and spring, declining in numbers during the late summer months, and increasing again during fall. Figure 9, the cumulative data for all 5 stations reveals the strength of this pattern. Average CPUE fluctuated greatly during the first half of the year, was consistently low during late summer, then remained high throughout the fall months.

The third pattern evident in CPUE data was a substantial fluctuation in the crab catches from stations D and E during the period April - July (Figure 8). During that period the usual occurrence was a large catch on neap tides, then a low catch during spring tides. Since pots were set on an alternating cycle of neap and spring tides, the effect produced was an alternating fluctuation in catch.

To test the hypothesis that tide cycles affected CPUE, multiple regression analyses were performed. Three independent variables were chosen: day number (1-365), Chehalis River output (cubic feet per second), and tidal exchange, in feet. Tidal exchange was defined as the sum of differences in slack tide levels during the 24-hour pot setting period. Values of CPUE for each of the 5 stations, and their cumulative average, were used as the dependent variables. Six regressions were made, one for each dependent variable. Twenty one complete sets of data from 1979 only were used. Results showed that tidal exchange did, indeed, account for a significant proportion of the variance in CPUE values from stations D (37.4%) and

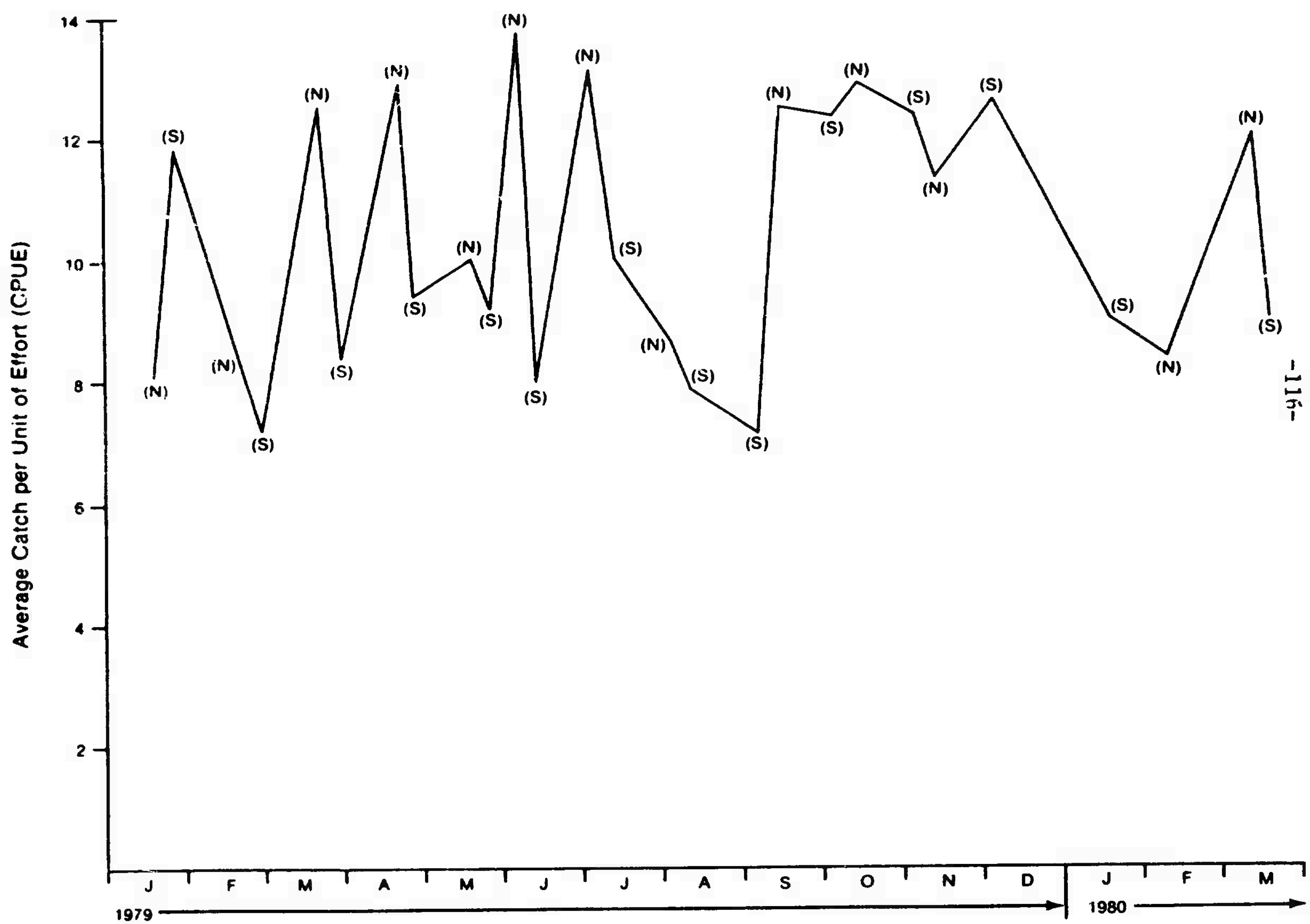


FIGURE 9. Cumulative average CPUE for all stations (A-E). Letters indicate Neap (N) or Spring (S) tide cycles.

E (19.1%), those being the stations where the spring tide effect was strongest (Tables 7-3 and 7-4). Surprisingly, day number accounted for over 55% of the CPUE variance at station A (significant at $p = 0.001$), and about 21% of the variance at station E (significant by itself at $p = 0.025$; in conjunction with tide exchange, $p = 0.012$). This finding arises from the general increase in crab catch throughout the year at station A, and a slight increase at station E, unnoticed prior to this test. Only station B was significantly influenced by river output, which accounted for 33% of the variance there. No independent variable accounted for more than 5% of the variance at station C.

Table 7-3. Results of multiple regression analysis.

	% of variance attributable to:			
Station	Tidal exchange	Day number	River output	All 3 variables
A	3.2	55.1	0.6	58.9
B	3.6	0.5	33.0	37.1
C	4.4	2.3	3.1	9.8
D	37.4	0.5	8.7	46.6
E	19.1	21.3	0.9	41.3
All	33.5	0.2	5.9	39.6

Regression coefficients (slopes) of the lines generated by the method of least squares were significantly different from zero for all stations except C (Table 7-4). Catch at station A

was positively correlated with day number, whereas catch at station B was negatively correlated with river output, although both equations had very shallow slopes. Crab catches at stations D and E were both negatively correlated with tidal exchange, as predicted; equations for these stations had high constants and steep negative slopes (Table 7-4). Station E was the only one to show significant dependence on more than one of the independent variables. The cumulative average CPUE values also showed a strong negative correlation with tidal exchange, probably due to the contribution of stations D and E to the average catch values.

Table 7-4. Best regression equations for CPUE data.

CPUE at station	= Constant +/- (slope) x (variable)	Significance (p)
A	4.06 + 0.0477 (Day)	0.000
B	9.82 - 0.0004 (River output)	0.008
C	No significant equation	--
D	22.93 - 0.3455 (Tide exchange)	0.004
E	24.34 - 0.2574 (Tide exchange) - 0.2701 (Day)	0.012
All	14.90 - 0.1387 (Tide exchange)	0.008

Salinity and Temperature Regimes

Bottom water temperature and salinity measurements were recorded during many different tide stages, from low to high slack. Therefore, rather than depicting consistent tide

levels, these data show almost the entire range of values occurring throughout the year. Salinity was highest, and most consistent at station E (Figure 10). At stations B, C, and D, salinities were lower and fluctuated considerably due to freshwater input from the Chehalis and Hoquiam Rivers. Station A not only exhibited the greatest range of bottom salinity (0-26 ppt), but was the only station exhibiting bottom salinities in the range of 0-9 ppt. Small crabs were caught at station A even in salinities as low as 0.0 (Feb. 28, 1979), 0.5 ppt (April 26, 1979), and 2.0 ppt (Feb. 9, 1980).

Temperatures showed a general increase from January through July, as would be expected (Figure 11). Bottom water temperatures rarely differed by more than 2°C among all 5 stations on any particular day. No salinity or temperature measurements were made during the period of August - October, while the original recording instruments were being replaced.

DISCUSSION

Crab pots were chosen as the sampling gear for several reasons. Unlike ring nets they could be fished in almost any weather conditions. Pot catches are generally not as variable as beam trawl catches, and pots could be used in areas where trawls tend to snag. Furthermore, pots could be left in place to fish over a 24 hour tide cycle, so catches should not have been affected by the level of tide at the time of setting, or by day/night differences in crab activity levels. Despite

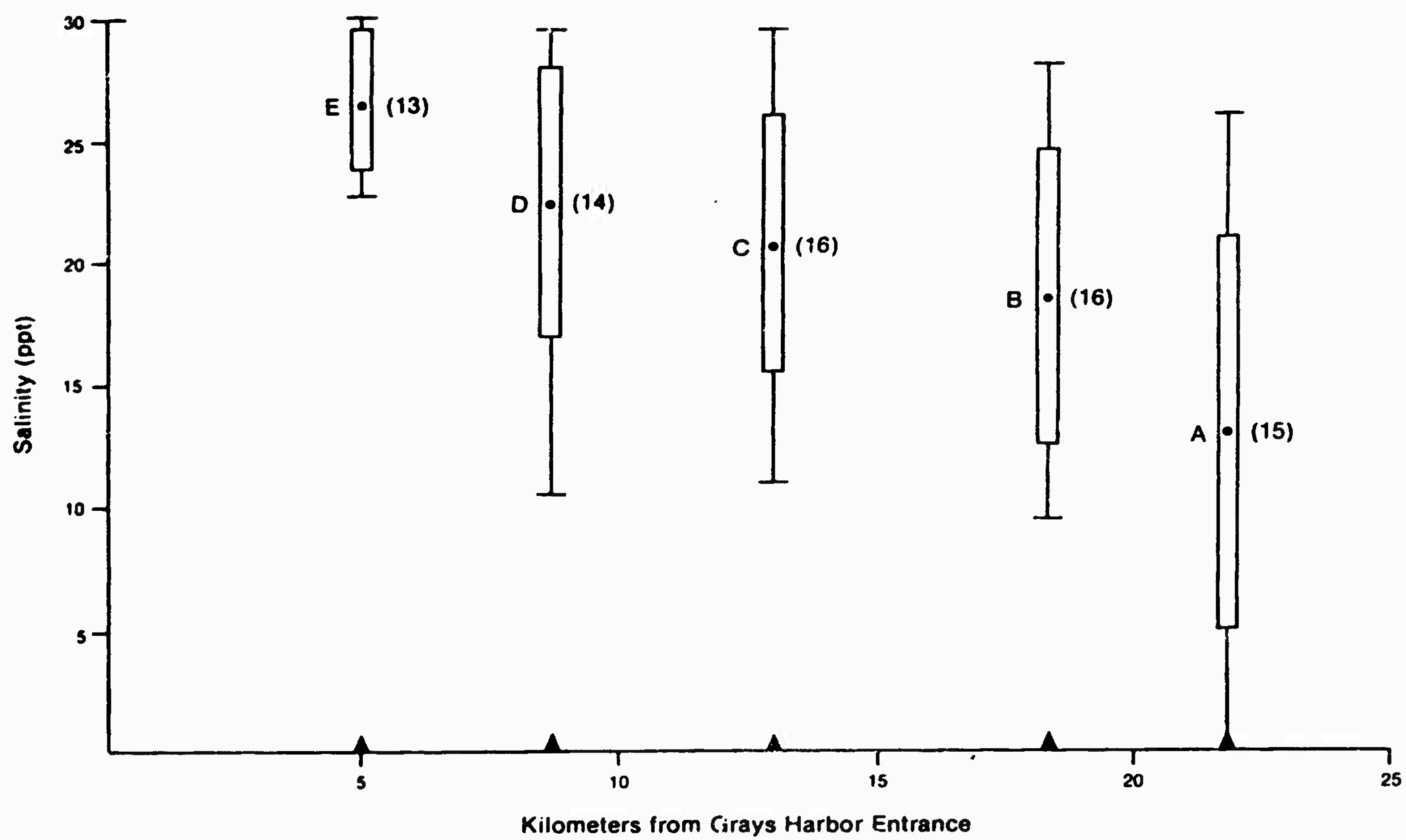


FIGURE 10. Salinity ranges of bottom water at crab sampling stations. Dot represents mean; inner bar is ± 1.0 standard deviation; outer bar is range. Number of observations is in parentheses.

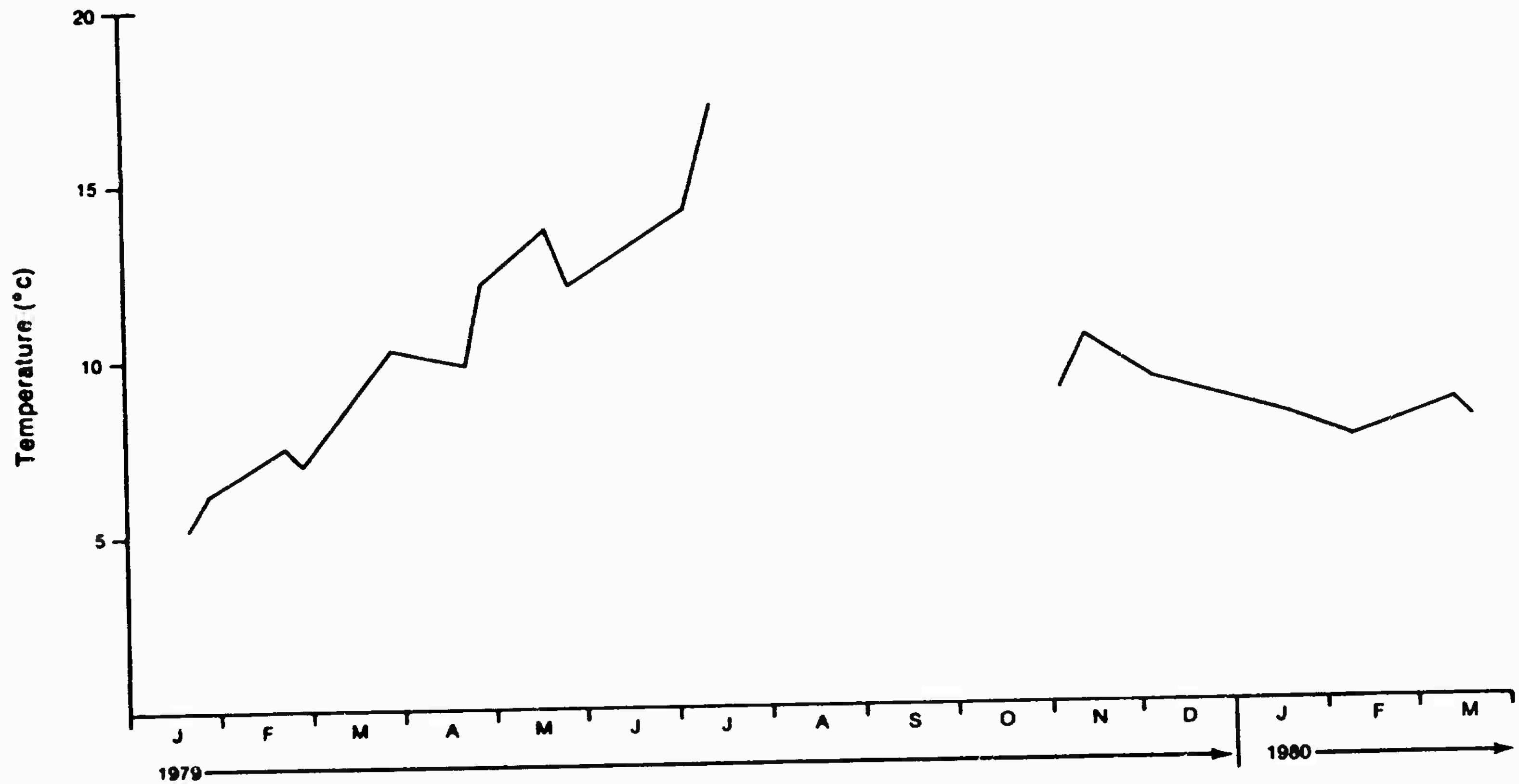


FIGURE 11. Average temperatures for all 5 crab sampling stations (A - E). No measurements recorded August-October, 1979.

these advantages, crab pots may not have sampled all sizes and sexes of crabs with equal efficiency, as a result of biases inherent in pot design and function. Several real trends were apparent, but many artifacts were produced.

There was a real difference in the distribution of adult and juvenile crabs. Although small crabs (<120 mm) were caught infrequently at stations C, D, and E, they may have been present in greater abundance than indicated, but not available to the gear if avoidance or cannibalism occurred. In contrast, it appears that large crabs may be prevented from using those parts of the channel upstream from station B, probably due to the salinity regime there. Since small crabs were caught at Cow Point (Station A) during periods of extremely low salinity, it appears that these juveniles may have an osmoregulatory capacity permitting them to utilize salinity ranges that cannot be exploited by adults. This mechanism could increase the foraging area for juvenile crabs, thus reducing intraspecific competition and, possibly, cannibalism of the young by larger adults. Different food preferences of juveniles and adults could also lead to such a differential distribution, but no data was collected during this study to support that hypothesis.

A slow increase in the average size of trapped crabs through the year was apparent at station A and, to a lesser extent, at station B. This increment was presumably due to growth. No size increase was apparent at stations C - E.

Crabs present at those stations, being 3 - 4 years old, should have molted synchronously (Mackay, 1942; Poole, 1967). This molting would, conceivably, have produced a sharp size increase at one point during the year, but was not apparent as such. It is likely that crabs migrate out of the harbor upon reaching maturity, which may account for the paucity of crabs larger than about 160 mm. Few females over 125 mm were recovered, indicating that they may leave the harbor at that stage, as suggested by Tegelberg and Arthur (1977).

The CPUE data did not lend itself to an analysis of crab movements, per se. Only a complete tagging and recovery program could record such events. However, some impressions could be made, albeit from limited evidence. During the months of July, August, and September, 1979, crabs were less available to the gear at stations C, D, and E (outer harbor). This could have resulted from a general inactivity, or actual movement of crabs away from those areas. The direction of movement, if any occurred, was not possible to determine. However, it appears that some large crabs (120-150 mm range) did move up river into the Cow Point area (station A) in summer, as shown by size frequency distribution diagrams (Appendices C-1 to C-5). These crabs could have been taking advantage of higher salinities present in the area during this period of low stream flows. In December and January, many larger crabs left the Cow Point area, presumably moving further downstream. The majority of those crabs were probably those that had matured during the

year from the 90-120 mm size group, but may have included some late summer invaders if the latter had not moved back downstream at an earlier time. It seems likely that high winter river flows could have lowered the salinity enough to cause a general downstream exodus. Minimum salinities were not recorded during the winter months because all measurements were made during the daytime, when higher tides prevailed. But stream flows do indicate the possibility of such conditions (Figure 12).

The spring tide effect, which resulted in lower catches during summer spring tide series than during neap tide series, was a curious phenomenon. Local fishermen suggested that the real causes of this effect were the strong tidal currents associated with spring tides, as a result of greater tidal exchange. According to these hypotheses, crabs were unavailable to the gear for three possible reasons: (a) they buried themselves in the sediment during high current periods, and were, therefore, less active, (b) strong currents buried the pots in sand making the pot triggers non-functional, or (c) such currents caused the odor of bait to be carried out in a narrow stream, rather than wafting out in all directions. No evidence was available to support any of these hypotheses, but the regression analyses did indicate the correlation between high spring tides and subsequent low crab catches.

Although slight seasonal variations in crab catch were observed, the magnitude of these variations was not nearly as

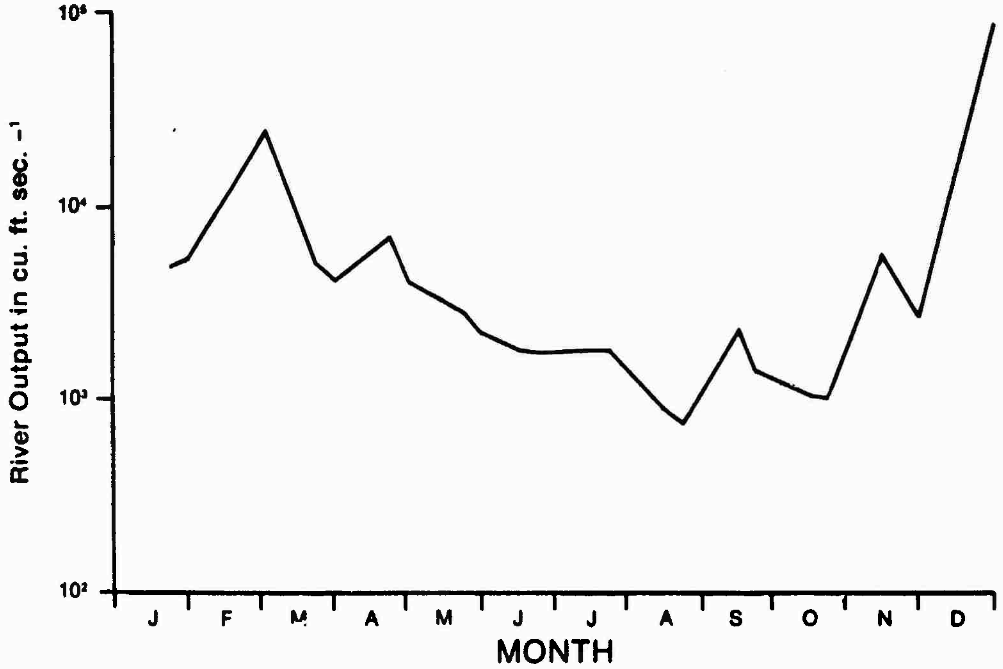


FIGURE 12. Chehalis River output, on dates of crab sampling in 1979. (Courtesy U.S. Geological Survey).

great as the differences observed between daily entrainment samples taken aboard the dredges. This between-sample variation was probably the result of local variance in crab population densities. Even the spring tide effect caused fluctuations in crab catch which were nearly as great as the largest seasonal fluctuations; sampling on both spring and neap tides was necessary to average out this effect. Therefore, a greater range of sample entrainment values was recorded from day to day, than would probably be observed among average values estimated during different seasons. Short term, small scale sample variance was greater than average long term variation would probably be.

SUMMARY

1) From January 1979 through March 1980, three crab pots were set twice monthly at each of 5 stations along the Grays Harbor Ship Channel. Information concerning crab sizes and catch per effect was obtained.

2) Average sizes of crabs were smaller in the eastern (inner) portion of the harbor, increasing with proximity to the harbor mouth. This information indicated the predominance of small crabs in the inner harbor, which probably functions as an important nursery area. This information also indicates the possibility that juvenile crabs might have greater tolerance for lower salinities, or better osmoregulatory capabilities, than adults.

3) At Cow Point, a general trend was apparent, consisting of low catches during late winter and higher catches during late summer. This may represent a winter downstream and summer upstream movement of larger crabs, as a means of avoiding lower salinities resulting from high river output during winter months.

4) Low catches were recorded in late summer at the outer harbor stations. No explanation for this could be derived from the available evidence.

5) Spring tides produced unusually low catches during the summer months at stations D and E (outer harbor). Regression analyses supported the hypothesis that catches were negatively correlated with tidal exchange. Several possible reasons for such an effect include avoidance of high current velocity by crabs and current-induced trap malfunction.

6) As expected, bottom water salinities showed a decreasing average value, with an increasing range of values as one moves upstream. Temperatures varied with season, but very little between stations.

SECTION 8

COMMENTS AND RECOMMENDATIONS

ENTRAINMENT ESTIMATION

The methods employed for sampling aboard the three suction dredges were all variations upon a single plan, i.e., the use of steel mesh baskets to strain the discharge. This method was effective for the collection of crabs and crab parts. The baskets were sturdy enough to withstand the high pressure discharge, but required intensive labor or heavy machinery to operate them. Mesh size appeared to be adequate, as crabs did not often break into pieces small enough to pass through the basket, whereas sand and gravel did pass through. Environmental sampling showed that the dredges entrained a representative sample of crab sizes present in the harbor. However, this data is incomplete regarding juvenile crabs (<50 mm width) which rarely appeared on dredges or environmental samples. They may have been absent from the areas sampled during the time sampling occurred (mostly October-March). This size class was too small to be collected by ring nets and might have broken into pieces small enough to pass through sampling baskets, thus they may have been overlooked. Fish were also retained well by the basket system, but no environmental fish samples were taken for size comparison, so very small fish (<50 mm length) may have been lost or overlooked during dredge sampling.

Splashing of dredge spoil out of the sampling baskets accounted for much of the sampling error, and some of the variability between samples. The assumption was made that discharged material lost by splashing was similar in constitution to that strained by the baskets, so that if only 75% of the discharge was actually strained, then only 75% of entrained crabs were retained in the baskets. No data was produced which could support or refute this assumption.

In summary, the method employed was shown to be an effective method of determining entrainment of crabs by hydraulic suction dredges. This method shows much improvement over the methods employed by Tegelberg and Arthur (1977) who used an airlift sampler and a dredge-water overflow screen. The overflow method has been shown to work well with fish, when used in conjunction with injection of live fish into the dredge intake arm, so there would be accurate entrainment data to compare with the recovery data (Dutta and Sookachoff, 1975a). Such a system seems unnecessary for the determination of crab entrainment rates.

Bet estimates of crab entrainment might be achieved through refinement of the techniques presented herein. Reduction of splashing would be a significant improvement, and will be attempted during further work on the pipeline dredge. Present plans also require reduction of mesh sizes to 12 mm (1/2 inch) in the sampling baskets, and the use of bottom

trawls of similar mesh size, in order to improve catches of very small crabs and fish.

MORTALITY ESTIMATION

Unfortunately, mortality could not be estimated as directly as entrainment. Mortality was estimated by comparing two distinct groups of crabs, those that were collected in the sampling baskets, and those collected by hand from the dredge spoil surface. It was recognized that these two samples were biased, the former due to sampling mortality, and the latter due to inability to efficiently locate dead crabs and parts by visual observation. Knowing only that these biases were in opposite directions, and having no data on the magnitude of either bias, they were averaged out. Survival tests then allowed estimation of delayed mortality, and removal of exposure-induced mortality.

Better estimates of true mortality might be made by improvements in two areas, reduction of sampling mortality, or better estimation of true mortality. The former seems unlikely without loss of sampling effectiveness. The latter might be possible by random selection and hand screening of small volumes of discharged sediment within the dredge hoppers, to better estimate those crabs killed or broken but not apparent on the spoil surface.

POTENTIAL EFFECTS OF FUTURE DREDGING

Tegelberg and Arthur (1977), employing two different methods, produced two different estimates for crab entrainment by the dredge BIDDLE - 400 or 1,000 crabs per hopper load of 3,060 cubic yards (cy), equivalent to 0.131 or 0.327 crabs/cy. No confidence limits were estimated.

Mean estimates of crab entrainment presented herein were close to 0.23 crabs/cy for three dredges, midway between the estimates made for the BIDDLE.

The effects of future dredging can now be roughly estimated from known entrainment/mortality rates of certain dredges. The dredges most commonly used in outer Grays Harbor are the BIDDLE, HARDING, PACIFIC, and SANDSUCKER. Entrainment rates for the latter two are known for the South Reach Channel (Table 6-3). The mean of 12 individual entrainment estimates (6 each for SANDSUCKER and PACIFIC) is 0.224 crabs/cy, and the 95% confidence limit is $\pm$ 0.103, i.e., $\pm$ 46% of the mean. Average crab mortality for the PACIFIC and SANDSUCKER is 64%. Therefore, the average potential crab mortality for suction dredges in the South Reach is 0.143 crabs/cy (0.64 x 0.224), assuming equal amounts of dredging are done by hopper and hopper-barge dredges (no schedule has been arranged at this time). Potential mortality for the MALAMUTE, typical of the pipeline dredges which operate in the uppermost channel reaches, was 0.0017 crabs/cy at Terminal 4 in Aberdeen (Cow Point Reach). No adequate data was gathered during this study for the

Crossover, Moon Island, or Hoquiam Reaches, but continuing research (USACE Contract No. DACW67-80-C-0086) has shown that crab entrainment by the SANDSUCKER in these reaches is approximately 10-20% of that in the South Reach for all sizes of crabs during summer of 1980 (James Hoeman, personal communication, September 10, 1980). All mortality rates considered in this paragraph represent winter conditions (November to March), and assume that day and night entrainment are equal (which is probably false, but no night samples were made).

The U.S. Army Corps of Engineers has proposed to enlarge the Grays Harbor navigation channel. Enlargement to the dimensions specified in the feasibility report (USACE, 1976) would require removal of 19.3 million cy of sediment, and annual maintenance dredging of 2.8 million cy. Table 8-1 lists the nine channel reaches to be dredged, organized into three groups (based on similarity of bottom sediment and salinity regimes), and the sediment volume to be removed from each group. Due to the environmental similarity, potential dredging-related crab mortalities are assumed to be equal within each group. The group 1 mortality rate is based on the South Reach. That of group 2 was not estimated due to inadequate data, and the group 3 rate is based on the pipeline dredge at Cow Point. Estimated volumes of sediment to be removed are given for each group of reaches (USACE, 1976).

Based on the values in Table 8-1, and the assumptions described above, the potential dredging related crab mortality for

Table 8-1. Estimated Crab Mortality for Proposed Dredging in Grays Harbor

Group	1	2	3	Total
Reaches	Outer bar Entrance South Reach	Crossover Moon Island Hoquiam	Cow Point Aberdeen S. Aberdeen	
Salinity[1]	20-33 ppt.	5-20 ppt.	0-15 ppt.	
Sediment type	Marine sand	Mixed	River mud	
Mortality rate (crabs/cy)	0.143	0.14-0.28	0.0017	
<u>Enlargement</u> Volume to remove (cy)	7,750,000	6,400,000	5,200,000	19,350,000
Total mortality (no. of crabs)	1,108,250	not estimated	8,840	1,117,090
<u>Maintenance</u> Volume to remove (cy)	1,000,000	1,500,000	26,000	2,760,000
Total mortality (no. of crabs)	143,000	not estimated	442	143,442

[1]Winter minimum to summer maximum (USACE, 1977)

the channel enlargement (excluding the Crossover, Hoquiam, and Moon Island reaches) is estimated to be 1.12 million crabs $\pm$ 46% (515,000). Subsequent annual maintenance dredging may cause a mortality of 143,000 crabs from these reaches, $\pm$ 46% (66,000). I believe this is a low estimate, and will probably change as information is gathered by ongoing research projects. Crab mortality in the middle reaches will add 10-20% to the

present estimate. Preliminary data from current research indicates that crab populations are greater in the outer reaches than in the South Reach area, and that summer entrainment is greater than winter entrainment. If the channel improvements require more than one year, these estimates could fluctuate due to seasonal and spatial variability in crab population densities. However, they serve to show the general magnitude of the mortality that could occur. Such a mortality could represent a considerable loss of production by offshore populations of *Cancer magister*, and a possible decline in the commercial fishery revenues.

It is now apparent that estimates of crab mortality for several dredges operating in various locations are not adequate for predicting the outcome of future dredging projects, unless several major assumptions are made. For better accuracy, every dredge to be used in Grays Harbor, and every reach to be dredged, must be sampled (though not in every combination). Data must be gathered on night vs. day, and winter vs. summer entrainment rates. For these purposes, more research is now being conducted by the University of Washington, in cooperation with the Washington Department of Fisheries, under USACE contract No. DACW67-80-C-0086.

SUGGESTIONS FOR REDUCTION OF DREDGE-INDUCED CRAB MORTALITY

Recommendations presented herein fall into three categories: alternative dredge types, alternative scheduling, and

physical modifications of dredges in order to reduce crab entrainment and mortality.

A. Dredge type. Clamshell dredges were shown to be least harmful to crabs. For channel dredging in areas populated by *Cancer magister*, clamshell dredges should be assigned first priority. Operating rates were similar to hopper dredges, so there should be little loss of productivity when used.

If suction dredges must be used for economic reasons, crab mortality might be reduced if their use is limited to those areas of the channel with silty bottom sediments, such as upstream from the intersection of the Crossover and North Channels. However, this statement is based on limited evidence and requires further investigation.

B. Dredge Scheduling. Seasonal variations in crab catch per effort (CPUE) data were interpreted to represent crab abundance in particular areas. Recommendations are based on this interpretive assumption. Low catches could also have implied only that crabs were unwilling or incapable of entering traps, as when crabs might bury themselves in the substrate and remain there for unknown reasons.

Crab abundance patterns differed between inner and outer harbor. The boundary line between these two areas appeared to be near station B (Hoquiam River) and can be defined as such for management purposes. Thus, recommendations are for two "activity areas".

Suggestions in this report refer only to entrainment of

Cancer magister. Dredging schedules must also consider other species, especially fishes, as well as other sources of information. Moreover, these suggestions required the flexibility to be altered as knowledge of crab populations improves. The present state of this knowledge indicates that crab mortality can be minimized by restriction of dredging to periods of low crab abundance, as described below:

1) In the channel east of the Hoquiam River, dredging should be avoided from September through November, coinciding with greater crab abundance during that period. Dredging may occur there during the remainder of the year when crabs are less abundant.

2) West of the Hoquiam River, dredging should take place in January through March, and July through September, corresponding with low crab catches in winter and summer. Dredging should be discontinued from April through June. This period coincides with greater crab catches and is a peak activity period for molting and mating. Crabs, especially females, would be most vulnerable at that time. Dredging should also be discontinued from October through December in the outer harbor, coinciding with increased crab catches then.

C. <u>Physical Modifications</u>. In order to reduce entrainment and subsequent mortality of *Cancer magister* by hydraulic suction dredges, certain modifications could be made to those dredges.

1) Splash plates now in use on some dredges (PACIFIC, SANDSUCKER) should be removed, or replaced with an alternative means of directing the flow of discharged sediment to desired locations in the hopper. A moveable nozzle at the terminal end of the discharge pipe might serve such a function.

2) Dragheads used by hopper dredges might be modified so as to deter the entrance of crabs, or frighten them away from the path of the dredge. Some suggestions follow:

   a) Physical disturbance of sediment in front of the draghead by a device similar to a plow or "cow catcher". If the upper 15 cm (6 inches) of sediment could be pushed up and off to the side by such a device, crabs on the bottom surface and buried in the sediment might also be pushed out of the way, or at least alerted to the presence of the dredge. A similar effect may have occurred when the PACIFIC and MALAMUTE were operating in soft sediment.

   b) Bright lights displayed from the front of the draghead might frighten crabs away. This

hypothesis is based on evidence that crabs avoid highly visible gear (Gotshall, 1978) and are often frightened away from lights held by SCUBA divers (personal observation).

c) There may also be some merit in investigating the use of electricity. Proper functioning of crab pots depends on correct grounding between the frame and wire mesh, indicating that crabs may be susceptible to electric fields. Further research would be necessary to determine if they are repelled by actual contact with the metal or by an electric field generated around the gear. Adaptation of such a mechanism might help repel crabs from the drag head.

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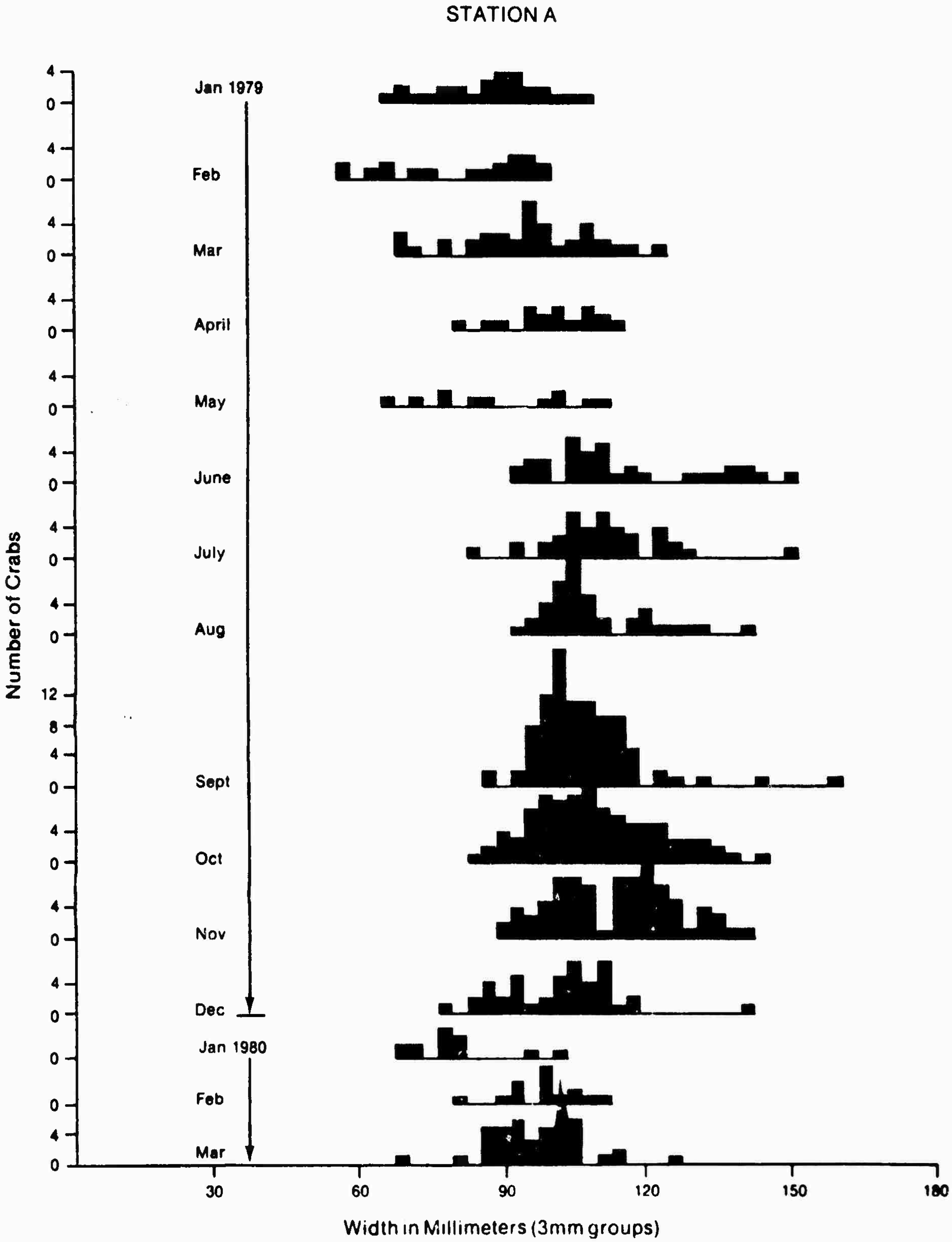
Appendix A. Location of VIKING samples.

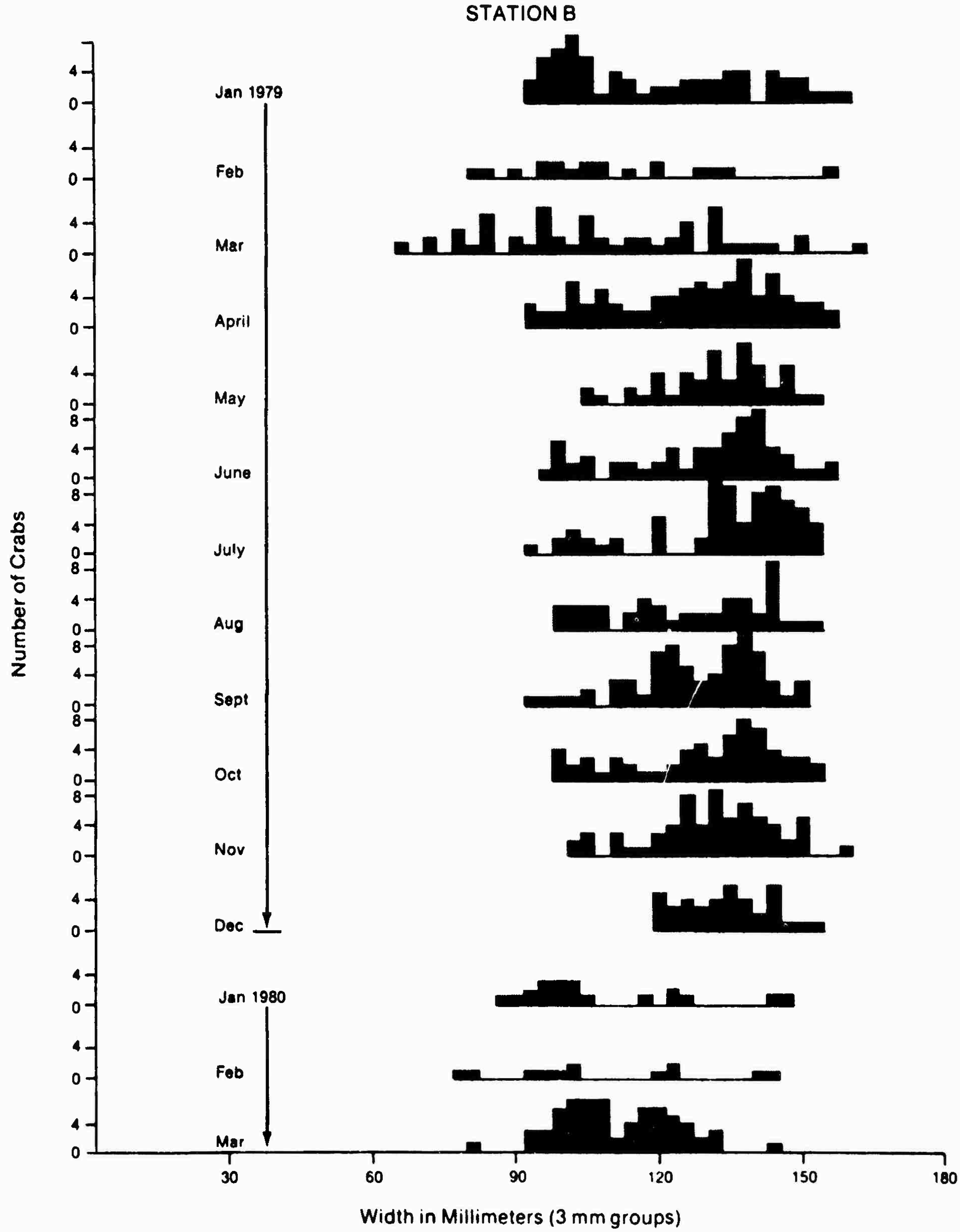
Date	# Sample	Location
10/14/78	1.1	North of new cut. Dredged 2 wks prior
	1.2	Center of cut. Dredged 2 wks prior
	1.3	Center of cut. Dredged within previous 24 hrs
	1.4	300 ft SE of center. Uncut area
10/21/78	2.1	Sta. 665, 100 ft SE of center. Dredged 3 wks prior by SANDSUCKER
	2.2	Sta. 666, on center
	2.3	Sta. 665, 390 ft NW of center. Uncut. Area probably affected by tug propwash
	2.4	Sta. 665, on center. Dredged 3 wks prior by SANDSUCKER
	2.5	Sta. 665, 390 ft SE of center. Uncut area
	2.6	Sta. 665, 260 ft SE of center. 200 ft NE of sample #2.5, in uncut area
10/28/78	3.1	Sta. 660.5, 320 ft SE of center. Uncut area
	3.2	Sta. 661, 320 ft SE of center. Uncut area. 50 ft SW of sample #3.1
	3.3	Sta. 661, on center. Dredged by VIKING 12-18 hrs prior
	3.4	Sta. 661, 40 ft NW of center. Dredged by VIKING 12-18 hrs prior
	3.5	Sta. 661, 100 ft NW of center. Uncut ridge between two VIKING cuts. Probably dredged by SANDSUCKER previously
	3.6	Sta. 661, 100 ft N of center 40 ft NE of #3.5
12/18/78	VIKING located opposite Buoy #35, on E side of crossover channel.	
	4.1	120 ft x 90° from VIKING
	4.2	130 ft x 135° from VIKING
	4.3	120 ft x 45° from VIKING
	4.4	140 ft x 270° from VIKING
	4.5	140 ft x 315° from VIKING
	4.6	155 ft x 210° from VIKING

Appendix B. Description and appearance of VIKING samples.

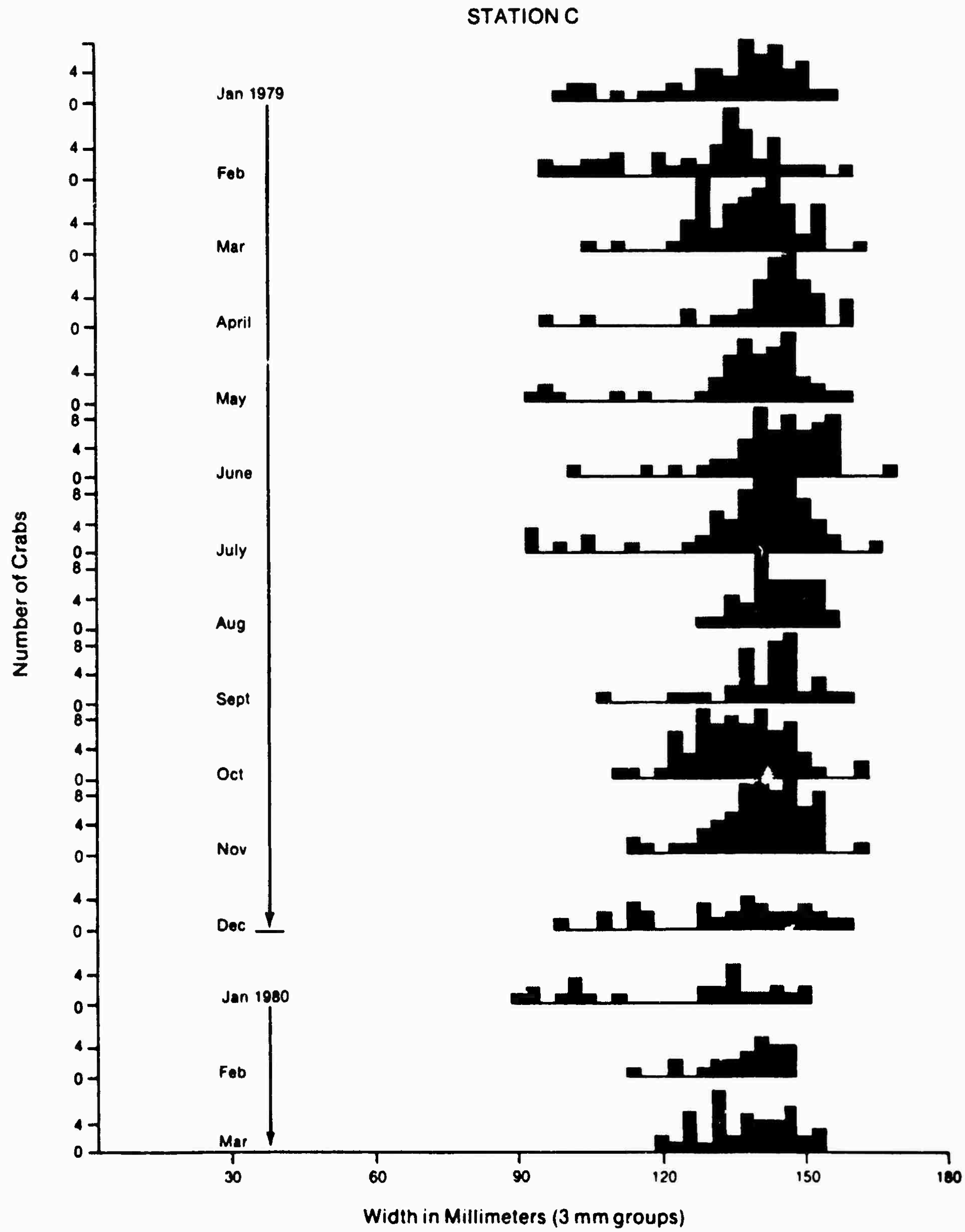
# Sample	Description
1.1	Dark sand; H_2S smell
1.2	Dark sand; H_2S smell
1.3	Dark sand; H_2S smell
1.4	Gray sand, black mud layer 9" below surface
1.5	Same as #1.4
2.1	Gray sand
2.2	Gray sand, some black mud; many old shells
2.3	Gray sand
2.4	Gray sand
2.5	Gray sand with broken shells
2.6	Gray sand, some mud; broken shells
3.1	Brown sand, some black mud
3.2	Brown sand, some black mud
3.3	Brown-black sand with shells, wood chips
3.4	Same as #3.3
3.5	Brown-black sand with about 20% mud; shells, sticks, and wood chips
3.6	Black sand and mud (50/50); shells, sticks, and wood chips
4.1	Brown-gray sand; black mud layer 1' below surface
4.2	Brown-gray sand and mud
4.3	Brown-gray sand; black mud layer below surface
4.4	Gray muddy sand
4.5	Gray sand, broken shells
4.6	Gray-black sandy mud



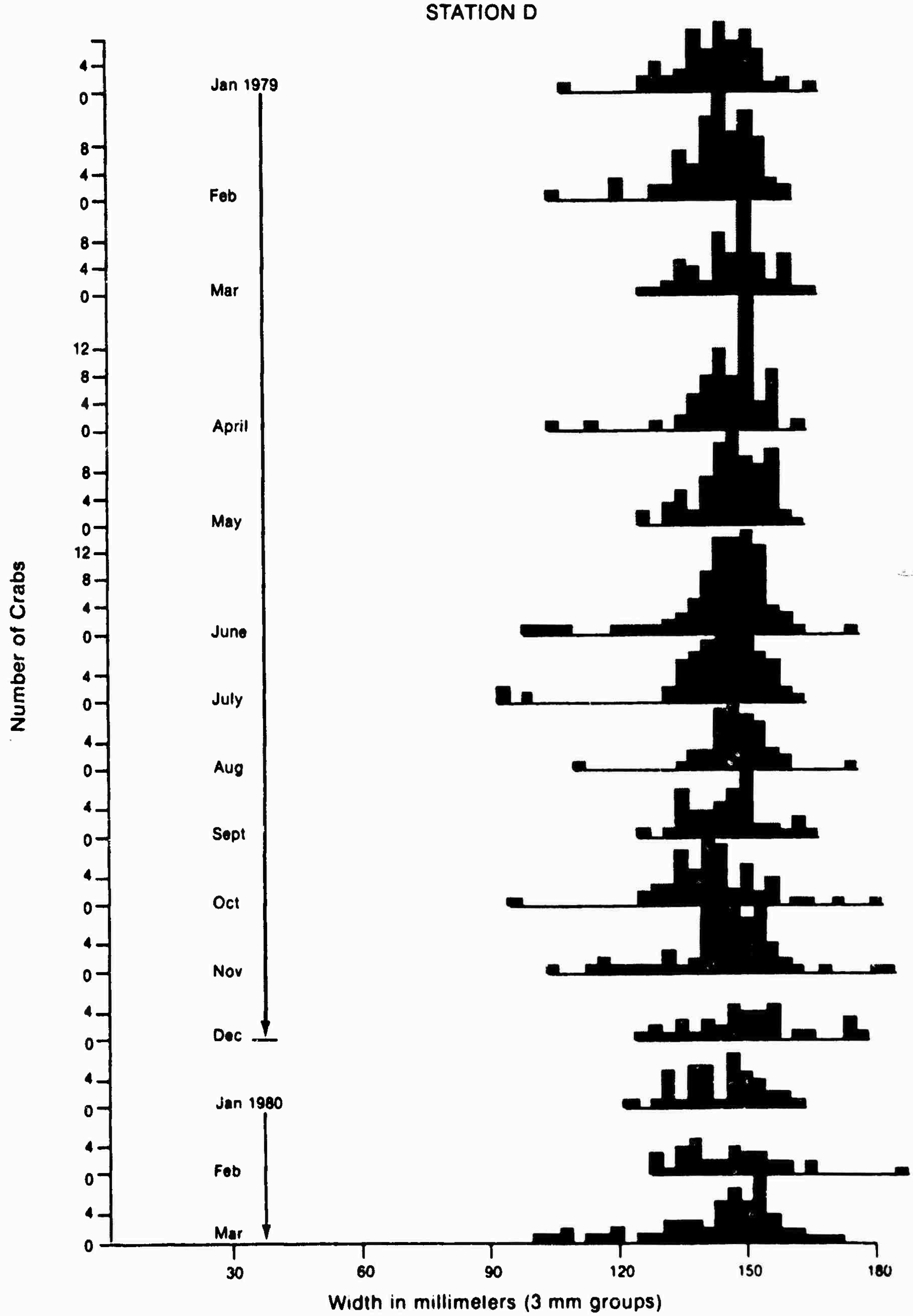
APPENDIX C-1. Size frequency distribution of crabs in pots, Station A.



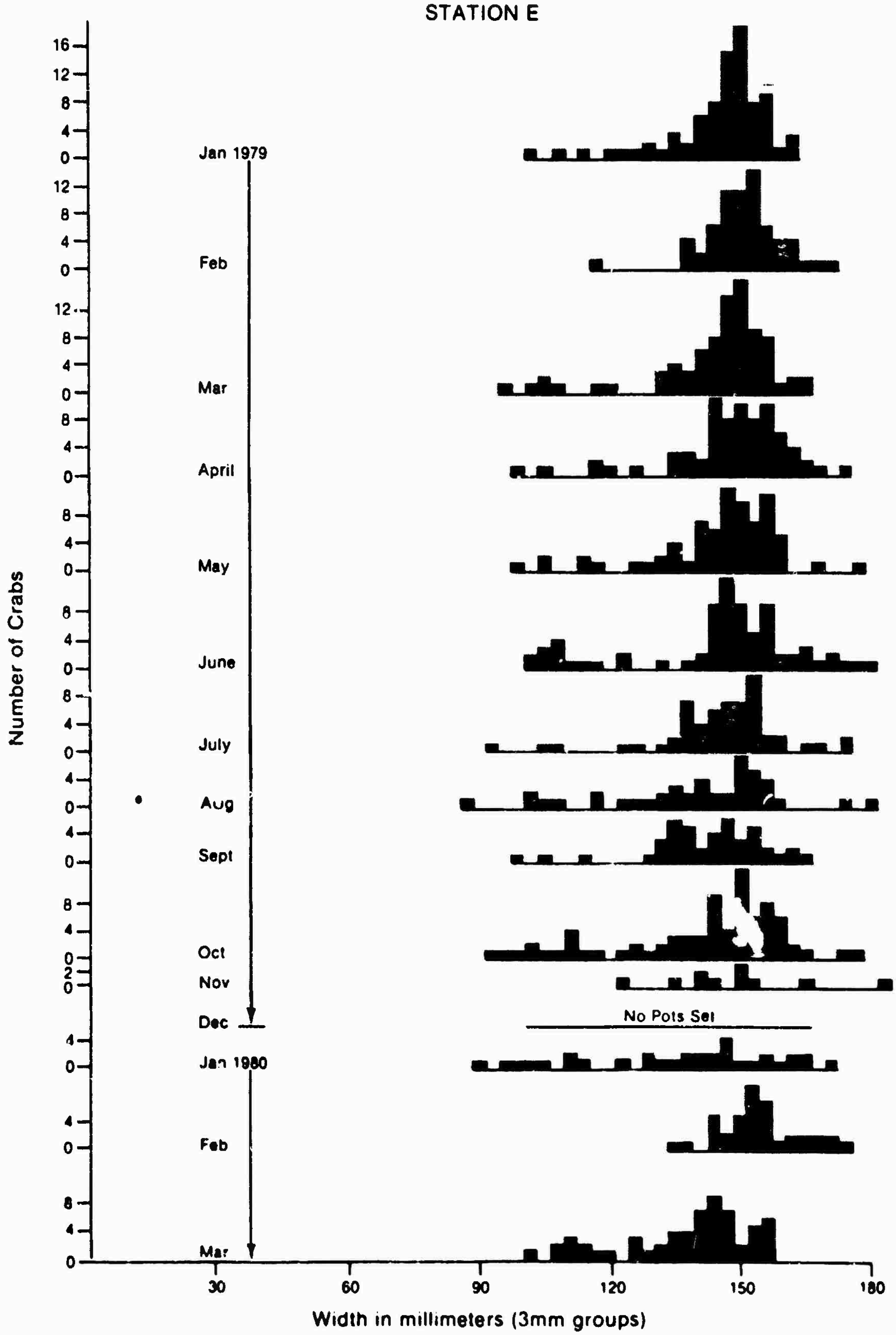
APPENDIX C-2. Size frequency distribution of crabs in pots, Station B.



APPENDIX C-3. Size frequency distribution of crabs in pots, Station C.



APPENDIX C-4. Size frequency distribution of crabs in pots, Station D.



APPENDIX C-5. Size frequency distribution of crabs in pots, Station E.